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INVESTIGATING CONSTRUCTION FALLS USING FAULT TREE ANALYSIS AND DEVELOPING A PROTOTYPE TOOL TO REDUCE FALLS USING EXPERT SYSTEM AND COMPUTER ASSISTED INSTRUCTION METHODS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

By

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* * * *

The Ohio State University 1998

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ABSTRACT

Construction falls have been identified as the most frequent cause of deaths and injuries to workers during construction operations. The objective of this study is to systematically analyze construction systems as they relate to fall protection safety and identify the potential hazards that may cause falls and slips. A fault tree analysis technique is used to identify all the possible events that may lead to falls in construction.

This knowledge is then incorporated into a prototype tool, SAFETY FIRST, that may be used to investigate construction falls, evaluate the factors that may contribute to construction falls, and train users on fall hazards and ways to avoid them. The system developed consists of the following four modules:

1. An expert system to investigate a construction fall that has already occurred. The system identifies a particular event or combination of events that are the likely cause of the fall and explains how it could have been prevented.

2. An expert system to evaluate the existing fall protection in a construction site. The system determines if the fall protection in a given elevated component is adequate and provides suggestions to eliminate or avoid any potential hazard identified.

3. An expert system tool that can be used at the design and planning stages of a construction project to identify and eliminate potential fall hazards at the early stages of the project.
4. A computer based training tool to educate workers on all aspects of fall safety. The training program will also maintain records on each of its users' performance.

In addition to the computer tool which can be used to tackle specific aspects of the fall safety process (i.e., investigation, evaluation, design and planning, and training), it is important to recognize that this kind of tool will be best used in a company whose environment already promotes safety as a major priority. Therefore, as a part of this study, we include a discussion of the elements that a sound, long term safety program should have in order to succeed.

The SAFETY FIRST system is expected to be used by private companies, such as general contractors and subcontractors, as a tool to identify potentially dangerous conditions, investigate falls, and train their employees; by government agencies, such as OSHA and BWC to investigate falls and to train their safety inspectors; and by academic institutions to train construction students in fall related matters. The system has been evaluated by experts and potential users. All evaluation criteria, including the overall performance of the system have been rated to be good or better than good.
Dedicated to my parents, brothers, and wife
ACKNOWLEDGMENTS

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In addition, I wish to thank all of the professionals who provided their time and effort to test and improve the program developed in this research. Special thanks go to Meg Conlon from the Builders Exchange of Ohio (BX) for her help in testing the program and gathering many of the professionals who did the final testing. I also thank
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CHAPTER 1

INTRODUCTION

1.1 Fall Accidents in the United States

A fall can be defined as a case when “a person loses his or her balance and moves from an erect position to a prone or semi-prone position” [Ellis 1989]. When walking, the body weight (i.e., center of gravity) is supported by the right or the left foot as one foot is moved in front of the other during the stride. This motion requires the walker to balance his or her body weigh on the support foot. Anything that upsets this balance can cause a fall accident. Fall accidents can be classified as follows:

- Same level falls: When the worker's fall starts and ends on the same working surface.
- Elevated or higher elevation falls: When the worker's fall starts on one level and ends on another.

Boths kinds of falls can result in injuries which can be as minor as contusions, and sprains, and as major as broken or fractured bones, cuts lacerations, and punctures. The most serious consequence of a fall can be the instant death of the worker or as a consequence of the injuries. Based on Accident Facts, published every year by the National Safety Council, Table 1.1 portrays the number of accidental deaths in the United States occurring between 1985 and 1992.
<table>
<thead>
<tr>
<th>CAUSE</th>
<th>1985 (^1)</th>
<th>1986 (^1)</th>
<th>1987 (^1)</th>
<th>1988 (^2)</th>
<th>1989 (^2)</th>
<th>1990 (^4)</th>
<th>1991 (^5)</th>
<th>1992 (^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation accidents</td>
<td>49,249</td>
<td>50,925</td>
<td>51,388</td>
<td>51,855</td>
<td>50,436</td>
<td>49,606</td>
<td>46,297</td>
<td>43,811</td>
</tr>
<tr>
<td>Total deaths due to falls</td>
<td>12,001</td>
<td>11,444</td>
<td>11,733</td>
<td>12,096</td>
<td>12,151</td>
<td>12,313</td>
<td>12,662</td>
<td>12,646</td>
</tr>
<tr>
<td>Poisoning by solids and liquids</td>
<td>4,091</td>
<td>4,731</td>
<td>4,415</td>
<td>5,353</td>
<td>5,603</td>
<td>5,055</td>
<td>5,698</td>
<td>6,449</td>
</tr>
<tr>
<td>Poisoning by gases and vapors</td>
<td>1,079</td>
<td>1,009</td>
<td>900</td>
<td>873</td>
<td>921</td>
<td>748</td>
<td>736</td>
<td>633</td>
</tr>
<tr>
<td>Complications with medical care</td>
<td>2,674</td>
<td>2,873</td>
<td>2,881</td>
<td>2,858</td>
<td>2,850</td>
<td>2,669</td>
<td>2,473</td>
<td>2,669</td>
</tr>
<tr>
<td>Fires and flames</td>
<td>4,938</td>
<td>4,835</td>
<td>4,710</td>
<td>4,965</td>
<td>4,716</td>
<td>4,175</td>
<td>4,120</td>
<td>3,958</td>
</tr>
<tr>
<td>Natural and environm. factors</td>
<td>1,904</td>
<td>1,501</td>
<td>1,527</td>
<td>1,798</td>
<td>1,816</td>
<td>1,453</td>
<td>1,292</td>
<td>1,232</td>
</tr>
<tr>
<td>Other accidents</td>
<td>16,674</td>
<td>17,099</td>
<td>16,573</td>
<td>16,359</td>
<td>15,588</td>
<td>14,966</td>
<td>15,054</td>
<td>14,279</td>
</tr>
<tr>
<td>Late effects and adverse drugs effect</td>
<td>847</td>
<td>860</td>
<td>893</td>
<td>943</td>
<td>947</td>
<td>998</td>
<td>1,015</td>
<td>1,100</td>
</tr>
<tr>
<td>Total accidental deaths</td>
<td>93,457</td>
<td>95,277</td>
<td>95,020</td>
<td>97,100</td>
<td>95,028</td>
<td>91,983</td>
<td>89,347</td>
<td>86,777</td>
</tr>
</tbody>
</table>


Table 1.1: Accidental deaths in the United States

From Table 1.1, it can be observed that falls are a leading cause of accidental deaths in the United States, causing between 12 and 14 percent of the accidental deaths, second only to transportation accidents. More important, the significance of fall accidents with regard to accidental fatalities has grown every year. Figure 1.1 portrays the total accidental deaths for the period between 1985 and 1992. From the downward curve, it can be observed that in general the total number of accidental fatalities has gone down over time. In contrast, Figure 1.2, which portrays the number of deaths caused by fall accidents
in the same period, shows an upward movement. Therefore, while the accident fatality rate in the United States has had a tendency to go down, the number of deaths due to falls has increased.

![Graph of accidental deaths in the United States](image1)

**Figure 1.1:** Accidental deaths in the United States

![Graph of accidental deaths due to falls in the United States](image2)

**Figure 1.2:** Accidental deaths due to falls in the United States

1.2 Accidents in the Construction Industry

The construction industry is one of the largest industries in the United States, making up about 10% of the country's GNP [Nunnally 1993]. The industry also
encompasses one of the largest labor forces in the country, accounting for about 6% of the private-sector work force (see Table 1.2). Unfortunately, the construction industry also accounts for one of the largest worker accident rates in the United States.

<table>
<thead>
<tr>
<th></th>
<th>1990¹</th>
<th>1991²</th>
<th>1992³</th>
<th>1993⁴</th>
<th>1994⁵</th>
<th>1995⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td>All industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>including</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of workers (x 1000)</td>
<td>117400</td>
<td>116400</td>
<td>117000</td>
<td>118700</td>
<td>122400</td>
<td>124400</td>
</tr>
<tr>
<td>No. of deaths</td>
<td>10500</td>
<td>9900</td>
<td>8500</td>
<td>9100</td>
<td>5000</td>
<td>5300</td>
</tr>
<tr>
<td>Death rates</td>
<td>8.9</td>
<td>8.5</td>
<td>7.3</td>
<td>7.7</td>
<td>4.1</td>
<td>4.3</td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of workers (x 1000)</td>
<td>6400</td>
<td>5900</td>
<td>5900</td>
<td>5900</td>
<td>6200</td>
<td>6500</td>
</tr>
<tr>
<td>No. of deaths</td>
<td>2100</td>
<td>1800</td>
<td>1300</td>
<td>1300</td>
<td>910</td>
<td>1040</td>
</tr>
<tr>
<td>Death rates</td>
<td>32.8</td>
<td>30.5</td>
<td>22</td>
<td>22</td>
<td>14.7</td>
<td>16</td>
</tr>
<tr>
<td>All industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>without</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of workers (x 1000)</td>
<td>111000</td>
<td>110500</td>
<td>111100</td>
<td>112800</td>
<td>116200</td>
<td>117900</td>
</tr>
<tr>
<td>No. of deaths</td>
<td>8400</td>
<td>8100</td>
<td>7200</td>
<td>7800</td>
<td>4090</td>
<td>4260</td>
</tr>
<tr>
<td>Death rates</td>
<td>7.6</td>
<td>7.3</td>
<td>6.5</td>
<td>6.9</td>
<td>3.5</td>
<td>3.6</td>
</tr>
</tbody>
</table>


Table 1.2: Worker deaths and death rates in the United States

Table 1.2 portrays the fatality rates for all industries versus that for construction industries for six years in this decade (i.e., 1990 to 1995). Throughout the period the death rate in construction was about four times larger than that for all industries combined. For example, in 1990, the death rate for all industries was 8.9 deaths per 100,000 workers, while that for construction was 32.8 deaths per 100,000 workers. Further, if compared to the death rate of all industries without construction, the rate in
construction was almost five times larger. It is clear that the death rate in construction
drove up the accidental death rates in the United States.

Further, considering worker injury rates, in 1990 *The Business Roundtable*
reported that the worker injury rate in the construction industry was about 54% higher
than the rate of all other industries combined [Business Roundtable 1990]. Despite the
significance of this number, it has been overshadowed by the numbers in the 1990s. Data
from the National Safety Council for the period between 1990 and 1995 indicates that the
disabling injury rates in the construction industry are now about twice as large as those for
all industries (Table 1.3).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>All industries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>including construction</td>
<td>No. of workers (x 1000)</td>
<td>117400</td>
<td>116400</td>
<td>117000</td>
<td>118700</td>
<td>122400</td>
</tr>
<tr>
<td></td>
<td>No. of disabling injuries (x1000)</td>
<td>1800</td>
<td>1700</td>
<td>3300</td>
<td>3200</td>
<td>3500</td>
</tr>
<tr>
<td></td>
<td>Disabling injury rates</td>
<td>1.5</td>
<td>1.5</td>
<td>2.8</td>
<td>2.7</td>
<td>2.9</td>
</tr>
<tr>
<td>Construction</td>
<td>No. of workers (x 1000)</td>
<td>6400</td>
<td>5900</td>
<td>5900</td>
<td>5900</td>
<td>6200</td>
</tr>
<tr>
<td></td>
<td>No. of disabling injuries (x1000)</td>
<td>210</td>
<td>180</td>
<td>300</td>
<td>280</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Disabling injury rates</td>
<td>3.3</td>
<td>3.1</td>
<td>5.1</td>
<td>4.7</td>
<td>4.8</td>
</tr>
</tbody>
</table>


*Disabling injury rate given as a percentage (%) of workers for each group and year.*

Table 1.3: Worker disabling injuries in the United States
1.3 Falls in the Construction Industry

Construction projects involve a wide range of operations and activities, most of which can lead to accidents if proper care is not taken. The most serious construction accidents involve construction equipment operation, trench and embankment failure, electric shock, collapse of temporary structures and forms, and falls. Of these accidents, falls have been reported to be the most prevalent cause of worker injuries and deaths.

A study was conducted by the United States Army Corps of Engineers (USACE) in 1992 based on 2578 construction lost-time injuries and fatalities included in the USACE accident report information system database for the period between 1984 and 1988 [USACE 1992]. They found that falls are a significant cause of deaths in construction, causing about 28 percent of the fatalities in the industry (i.e., 20.9 percent due to falls from elevation and 6.9 percent due to falls from the same level) (Figure 1.3).

![Pie chart showing construction fatality causes]

Figure 1.3: Construction fatality causes, based on the USACE database [1992]
In 1990, the Occupational Safety and Health Administration (OSHA) also performed a study to investigate the causes of construction fatalities and trends associated with them [OSHA 1990]. The study used work-related fatalities recorded between 1985 and 1989 and stored in OSHA’s database. The database included 3496 fatalities for the given time period. Table 1.4 and Figure 1.4 show the distribution of these fatalities according to their cause. By far, falls were the most prevalent cause of deaths, accounting for 33 percent of them (i.e., 1148 deaths).

<table>
<thead>
<tr>
<th>CAUSE</th>
<th>TOTAL FATALITIES (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Struck by/against</td>
<td>23</td>
</tr>
<tr>
<td>Fall from elevation</td>
<td>33</td>
</tr>
<tr>
<td>Caught in/between</td>
<td>18</td>
</tr>
<tr>
<td>Shock (electrical)</td>
<td>17</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 1.4: Construction fatality causes, based on the OSHA database [1990]

Figure 1.4: Construction fatality causes, based on the OSHA database [1990]
In 1994, Culver and Connolly performed a similar study of the OSHA database information. However, their study was based on 5964 construction fatalities recorded between 1985 and 1993. Unfortunately, their study found no improvement. Falls still caused 33 percent (i.e., 1954) of the construction accidental deaths. The distribution of the other causes remained much the same as those obtained from the previous study [Culver and Connolly 1994].

Concerning injuries in the workplace, the USACE [1992] study found that “falls from the same level (10.3 percent) and falls from elevations (20.4 percent) caused 30.7 percent of the total lost time injuries” [USACE 1992]. Therefore, falls were still the main cause of injuries in construction, about 10 percent larger than the second most frequent cause, being struck by an object or equipment, which represented 22.3 percent of the injuries.

![Construction injury causes](image)

Figure 1.5: Construction injury causes, based on the USACE database [1992]
In 1992, the U.S. Department of Labor conducted another study of worker injury rates in construction [BLS 1992]. The study included construction injury claim records for the period between 1985 and 1989 and was based on workers' compensation data obtained from the Bureau of Labor Statistics (BLS) (i.e., 1985 and 1986 data) and the National Technical Information Service (NTIS) (i.e., 1987 and 1989 data). The analysis found that fall accidents accounted for 21 percent of the injuries within the study period (i.e., 14 percent due to falls from elevation and 7 percent due to same level falls). These injuries are second only to those caused by struck by accidents.

More recent construction injury data indicates that fall accidents are still a significant cause of non-fatal occupational injuries involving days away from work. Table 1.5 shows injury data for 1992, 1993, and 1994. This data indicates that falls are the cause of about 20 percent of the injuries in construction.

<table>
<thead>
<tr>
<th>Type of Falls</th>
<th>1992 1</th>
<th>1993 2</th>
<th>1994 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall to same level (%)</td>
<td>6.5</td>
<td>7.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Fall to lower level (%)</td>
<td>11.9</td>
<td>11.6</td>
<td>11.3</td>
</tr>
<tr>
<td>Slips, trips (%)</td>
<td>3.1</td>
<td>3.4</td>
<td>3.1</td>
</tr>
</tbody>
</table>


Table 1.5: Non-fatal occupational injuries caused by falls in construction

The injury rates will vary for different trades in the industry. For example, in 1994, statistics from the NSC show that 205 out of 578 fatal occupational injuries occurring to people in construction trades (e.g., supervisors, carpenters, electricians) were due to falls.
This accounts for over 35% of the total fatal occupational injuries that occurred in this group. Furthermore, for construction laborers, 46 out of 226 fatal occupational injuries were due to falls (i.e., over 20% of the injuries). As for the nonfatal occupational injuries in construction, 6.5% of them are due to falls at the same level, 11.9% are due to falls to lower levels, and 3.1% of them are due to slips and trips [NSC 1994].

All of these injury and fatality numbers prompted the researchers from OSHA, USACE, and BWC to indicate that special attention should be paid to falls in construction. "The number of construction fatalities due to falls warrants special attention. Employers need to focus on avoiding the risk of falls during the planning and execution of construction activities, and they need to plan enforcement activities that eliminate fall hazards" [Culvert and Connolly 1994].

1.4 Costs of Construction Accidents

Today, safety professionals believe that the high injury and death rates are in part due to the disregard for safety in the construction site. Often construction company managers do not regard safety as a vital factor in the success of a construction project, especially if money must be spent. Therefore, safety equipment is often not available in construction sites. Complicating the matter further, it is often the case that both supervisors and workers believe that the use of safety equipment or use of safe procedures will interfere with production (i.e., slow them down). As a consequence, safety equipment is not used even when it is available in the site.
Unfortunately, this attitude shows a lack of foresight and prudence on the part of managers given the costs that the lack of safety on a given construction site can entail. The national Safety Council estimates that “occupational hazards cost U.S. businesses $43 billion in 1987. All accidents nationwide cost more than 133 billion or approximately 3 percent of the gross national product (GNP)” [Noble 1991].

Among these costs are the ones directly generated from the accident which include medication costs, medical services, hospitalization, and disability compensation. Most of these costs are covered by the worker's compensation insurance. The following statistics from the National Safety Council [1994] help to illustrate the direct cost of work-related accidents. Over 42.2 billion dollars of worker compensation benefits were paid to disabled workers in 1991. This amount consisted of wage compensation benefits (about 25.4 billion dollars) and medical and hospital costs (about 16.8 billion dollars).

For most construction companies these costs are reflected in the worker's compensation insurance premiums they pay. Today, “The cost of workers' compensation for many construction companies is comparable to their total profits.” [Levitt and Samuelson 1993]. The reason for this high costs is that contractors often ignore these expenses because they believe that the workers' compensation rates are fixed. While in fact, under the worker's compensation method, the premiums companies have to pay are not fixed, but vary depending upon their own accident rate history. The better the safety record of the company, the lower the rates it will have to pay. The opposite also holds true, companies with bad accident records will pay higher rates.
Workers' compensation is a form of ‘no fault’ insurance. It “was developed to provide a no-fault plan for dealing with industrial injuries. Under it employers provide insurance that pays for medical treatment, rehabilitation costs, and losses to the worker or his/her family resulting from the injury” [Levitt and Samelson 1993]. In exchange to these benefits, the worker gives up the rights to sue his or her employer for negligence. Thus, eliminating some legal fees related to lawyer fees, trials, and appeals.

These laws tried to encourage employers to pay more attention to safety through the use of the experience modification rate (EMR) mechanism. To encourage safe behavior, under this system employers with good accident records would be rewarded by having to pay lower costs and while the opposite would be true for contractors with poor records. Therefore, workers’ compensation costs consist of two main components:

1. A manual rate is based in the industry sector’s medical costs and benefits paid out in the previous year for each type of work (average) plus an amount to cover administrative costs of the insurance provider. This rate varies from year to year and is the same for all the contractors in the same type of work (e.g., plumbing, electrical, general contractors).

2. The experience modification rate (EMR or X-mod) is the component that modifies the cost of workers’ compensation according to the contractor’s accident history.

The experience modification rate (EMR) is calculated separately for each contractor based on his or her individual losses and it is used to modify the manual premium cost. It increases the premiums for contractors with more claims than the average and lowers it for contractors with lower than average claims. For example, an
EMR of 75 indicates that this contractor had a lower than average number of claims and therefore he or she will pay 75% of the manual rate (i.e., saving 25% of the cost).

The X-mod range widely among contractors. For example, for contractors in California X-mods ranged from 35 to 260 [Levitt and Samelson 1993]. Therefore, some contractors (i.e., unsafe) will have workers' compensation costs four to seven times higher than those of their safer competitors. In a competitive bidding environment, this cost difference is a handicap acting against the contractor with the higher X-mod.

The construction industry has one of the highest premiums for worker compensation. This is not surprising, given the high injury and death rates in the industry. According to the NSC, deaths due to falls in the workplace cost employers about seven billion dollars in 1990, while disabling injuries cost them another 950 million dollars [Rademaker 1991].

In addition to the direct costs, every accident incurs indirect costs. Among these costs are wages paid to the worker for time not worked, losses of the injured worker’s productivity, losses of time and productivity of the worker’s crew and the crews working in the vicinity of the accident, losses of supervisory and administrative time, losses of working time for accident investigations, the cost of hiring and training a temporary replacement worker, the cost of overtime required to recover loss time, and the cost to clean up and repair damaged equipment and material, among others [Hinze 1990, Hinze and Applegate 1991, Levitt and Samelson 1993].

Several studies have tried to quantify the indirect costs of accidents. The business roundtable [1990] estimated that these indirect costs are between 4 to 17 times the total
for direct costs. A study done by Stanford University in 1979-1980 estimated that the average ratio of hidden costs to direct costs could be as much as four to one, or higher [Stanton and Willenbrock 1991].

In 1990, Hinze also performed a study to quantify these indirect costs of injuries [Hinze 1990]. He designed a survey form to be completed at the job site by someone who would monitor various indirect costs associated with each injury. The forms were collected over a nine month period and a total of 573 returned surveys, which represented 185 construction projects. The study determined that the ratio of indirect to direct costs ranges depended on the seriousness of the injury. For minor injuries (i.e., medical case injuries), the ratio of indirect/direct costs was determined to be equal to 4.2:1—a number which is consistent with the commonly accepted 4:1 ratio. However, for more serious injuries (i.e., restricted activity/lost workday cases), the ratio was found to be 20.3:1, which exceeds far the 4:1 ratio.

Nowadays, these ratios may be on the rise, given the increase of the number of accident cases going to court. In many cases courts have ruled against the original concept of workers’ compensation, allowing workers to bring liability suits against their employers. Furthermore, injured employees of subcontractors have also began to sue both general contractors and owners and as a consequence “a suit resulting from serious injuries can result in costs of millions of dollars” [Levitt and Samelson 1993].

Finally, in several states, during the past 10 years, district attorneys have been more willing to resort to criminal actions against the contracting company’s owners and manager in cases when there has been an occupational fatality or serious injury. For
example, "law enforcement officials in Los Angeles take industrial fatalities so seriously that they have formed a special prosecution unit to make employers liable for their actions" [Noble 1991].

1.5 Special Problems Related to the Construction Industry

As discussed before, even though the construction workers constitute only about 6 percent of the country's work force, their death rates are about four times larger than those of workers in other industries [NSC 1991-1996]. Their disabling injury rates are about twice as large as those for workers in other industries [NSC 1991-1996]. Hinze blames this dismal safety record on the fatalistic view that construction work is inherently dangerous and injuries will occur. He argues that this view excuses the industry for its poor safety record. Further, he argues that "it is appropriate to consider construction work as inherently dangerous if no proactive steps are taken to improve the work conditions and to ensure that the work is undertaken in a safe manner." [Hinze 1997].

Unfortunately, these attitudes and the practices that go with them have been slow to change. In their Construction Hazard and Safety Handbook, King and Hudson go to the extreme of concluding that based on the U.K. experience "it would appear that the construction industry is not destined to learn from its mistakes. Given that in this country ‘falls of persons from heights’ has accounted for over half the fatal accidents in construction during the last decade one is inevitably drawn to the conclusion that the industry will never come to terms with basic principles of accident prevention. More alarming though is that such circumstances in an industry which practices methods of
working which have changed little over the decades and in some cases over ‘centuries’” [King and Hudson 1985].

In the most recent years, after the OSHA act took effect and the government started regulating industrial safety, the number of deaths and injuries in the industry has been reduced; unfortunately, the improvements have not been better that those achieved in other industries. Therefore, the death and injury rates in construction when compared to those in other industries have remained unchanged or worsened. One of the problems with the use of regulations to control safety in the site is that the legislative language of codes and regulations tends to be unintelligible to the layman and that no subject can be covered comprehensively and in fine detail using such language. Further, the industry is the fragmented into a large number of small contractors which specialize in certain parts of the job. It is more difficult for OSHA inspectors to monitor the work and practices of a large number of small firms than to monitor a smaller number of medium to large sized firms [King and Hudson 1985]. Therefore, there is still a need for self-regulation within the industry as a way to improve safety.

Other conditions and problems faced by the construction industry that set it apart from other industries are the following [King and Hudson 1985]:

1. The temporary duration of work sites combined with the rapidly changing nature of the work and hazards associated with it. Given that the job and its hazards are continuously changing (even from day to day), safety precautions need to be updated continuously. Therefore, periodical inspections (i.e., by-weekly, monthly, or yearly), either by OSHA or in-house inspectors, will fail to detect or confront certain hazards.
Therefore, they should be controlled by someone in the site. Further, different job sites imply different hazards to be recognized and overcome. Therefore, for a period of time, all workers are new to the working environment.

2. The seasonal employment. As a result of weather conditions, a great amount of the construction work takes place at certain seasons favorable to construction work (e.g., summer). This may lead to a constant change of labor which on slow work seasons may move to other regions or more stable jobs in other industries.

3. The high labor turnover rate. This is caused by the temporary nature of construction and the season effect which causes workers to move from site to site. "A high labor turnover in any job is not conductive to a good safety and health record. It also leads to workers leaving a job before they are properly conversant with most of its details, including safety, while the employer is constantly faced with the need to train new workers" [King and Hudson 1985].

4. The small size of construction firms. Small firms "cannot afford the services of safety specialists or instructors, so that there is little opportunity for organized safety instruction, whether on or off the job ... Many small firms are short of capital and under greater pressure than larger ones to cut costs at the expense of safety" [King and Hudson 1985].

5. The extensive use of subcontractors in the industry. This causes problems of coordination, planning, and allocation of safety responsibilities. Further, the fragmented industry encourages the attitude of shifting responsibility and blame once an accident occurs.
6. Competitive bidding. The emphasis of the industry on competitive bidding and the lack of specification for safety requirements in the contract documents places pressure on contractors to lower their bids at the expense of safety. Contractors who account for safety costs on their bids may end up being penalized by not providing the lowest bid and as a consequence not getting the job.

Of these conditions, the first three items may have contributed to the high injury and fatality rates existing in construction by leading to the presence of a high number of workers which are new to the working environment at all stages of construction projects. The USACE study of construction accidents found that “workers experience a higher percentage of accidents during their first few months on a particular job site regardless of age ... (and that) younger workers and workers new to the job experience a higher percentage of injuries during their first few months on a particular job site” [USACE 1992]. Research by Levitt and Samelson [1993] also found that new workers (i.e., workers new to the project, regardless of age or experience) are an especially vulnerable sector of the workforce, accounting for 25 percent of all construction accidents. Both studies concluded that a dramatic reduction in accidents could be obtained by providing additional safety training and controlling the risk exposure to new workers.

In addition to the newness to the environment, another factor affecting the industry’s safety records is that in search for more stable jobs, many workers move to jobs in other manufacturing industries. Currently, this trend is accentuated by the booming economy, in their 1998 forecast for the industry, Engineering News-Record indicates that
“people don’t want to come into the industry because there are a lot of opportunities out there in other industries” [ENR 1998].

As a consequence, many of the industry’s in-coming workers are not trained in safety. Further, because of the existing variability in the emphasis put on safety by contractors, certain workers may have received good safety training, while others may have no training at all. King and Hudson also point out that the number of untrained workers (i.e., without formal training) within specialty trades is growing at the present time. Research of accidents in the construction industry supports this conclusion. According to OSHA [1990], 71 percent of the fatalities caused by falls occurred to workers of specialty trade (SIC 17) contractors (i.e., roofing, siding, sheet metal work, masonry, stone work, tile setting and plastering, and painting), 15 percent occurred to contractors working on building construction (SIC 15), and 14 percent occurred to contractors working on heavy construction other than building construction (SIC 16). Another study also found that the specialty trade contractors group (SIC 17) “accounts for about 60 percent of the construction work force but 72 percent of the fatalities” [Culvert and Connolly 1994]. Therefore, there is “a special need for HS instruction both at the workplace and in classes where films and other audio-visual aids can be used” [King and Hudson 1985].

According to Hinze [1997], managers and supervisors have the ability to influence the working conditions; however, in order for them to do so, they must have the knowledge of how to improve these conditions, the tools to implement a safe environment, and the willingness to use them. Most construction managers rise through
the company ranks or come directly from college. In the first case, they are expected to acquire most of their knowledge earlier in their careers as workers (additional training may come from personal readings, attendance to seminars and conferences organized by trade organizations or their employer). Therefore, in many cases, they have not received the safety training they need or, worse, have been taught that safety is not a priority. In the second case, during their college education, “all technical training in construction is involved with the ultimate safety of the buildings or other works of construction and their users, but unless a special effort is made, it tends to be less concerned with the safety of the workers” [King and Hudson 1985]. Thus, these managers may also lack qualifications to recognize the importance of safety.

Recently, the importance of construction safety and safety training has been recognized. According to the ENR forecast for the industry in 1998, the “debarment regs” may put restrictions on contractors bidding for “federal projects if they have any black marks related to safety or labor relations. That means that contractors cited for a federal safety violation may not be eligible to compete for a federal contract” [ENR 1998]. Further, “contractors can expect to see a new attitude by owners in assessing how they train people and exactly how the contractors expect to staff those projects” [ENR 1998]. It is expected that owners will follow the Business Roundtable recommendation that they prequalify only those contractors that train their workers significantly.

Further, in 1991, the Construction Industry Institute (CII) announced a program to achieve a reduction of accidents by 25 percent by the year 2000 [CII 1998]. In order to achieve this objective, they indicate that research should be focused on areas such as
adoption of new technology (e.g., computer applications) which is responsive to the
industry's needs, exploring new approaches to training the construction workforce and
improve safety in general, and provide ways to globalize information (e.g., standarize the
information and make it easily available to all construction firms).

1.6 Computers in Construction

Though there were several areas where computers could have been applied and
applications already existed for such tasks (e.g., CPM scheduling), the overall success of
computers in construction remained below early expectations well into the 1980's.
Currently, the use of computers has become more widespread in the industry. Reasons for
this trend include: lower costs of computers, powerful and easy to use software, the ease
of interpreting output formats, and the increase in the number of people familiar with
computers. "Even so, the impact of computer technology has only begun to be felt ...
Computers can assist us in almost all aspects of construction engineering and
management, for example, estimating, scheduling, operations simulation, safety, structural
analysis, and even direct field applications like automated data collection and robotics."
[Paulson 1995].

Computers are currently used in management and administration tasks, such as
keeping accounting and payroll records, project planning and scheduling, and materials,
equipment and human resources management, among others. Engineering tasks have also
taken advantage of computers to perform tasks, such as estimating, field surveying and
layoff operations, and computer-aided design and drafting, among others.
Despite these applications, computers are still underutilized in the industry. Paulson [1995] points out that the areas of safety and health could greatly benefit from using computer’s technology, including artificial intelligence and multi-media training:

A particularly important and promising area where expert systems could help out is occupational safety and health ... The main reason for trying to apply AI and, specifically, expert systems to construction is to deal with the qualitative and judgment-based types of problems that are prevalent in this industry. Perhaps the most valuable asset for a construction professional is not mathematical or scientific skills of the type taught in engineering schools but rather is experience and the good judgment to use that experience to solve new problems. One major objective of construction artificial intelligence researchers is to capture this type of experience in computer programs so that other computer engineers can access it and apply it, perhaps even after the experts who provided the knowledge are no longer available. Such programs also provide a means to integrate and validate the knowledge and experience of many experts and thus provide a means for accumulating and improving a body of knowledge over time.

Computers are severely underutilized for training in construction; but recently, powerful user-guided multimedia educational systems with lots of graphical interaction, and even sound and video pictures to enhance the presentations, have made this type of training interesting and attractive to a wide range of users. Furthermore, relative to the cost of hiring instructors and bringing people together in conference rooms, computer based instruction can be economical and effective, and it can take place at workstations right in the field.

Nowadays a computer system already includes the devices to play and operate most multimedia programs, such as a CD-ROM, a video interface which will display both text and graphics, sound cards and speakers to play and capture sounds, and the capability to capture, store, and play video clips.
1.7 Objectives

Many factors, such as the skill of workers, the attitude and health of workers, the condition of the structure components, the weather conditions, the types of construction equipment, and the availability and condition of safety equipment affect construction safety. A working environment is "provisionally categorized as safe if its risks are deemed known and in the light of that knowledge judged to be acceptable" [King and Hudson 1985]. The identification of the potential hazards that may lead to construction fall accidents is mandatory to reduce the risks of such accidents and, subsequently, create a safer construction site.

These hazards could be identified by using one of two approaches: first, by investigating fall accidents after they occur, or, second, by identifying potential hazards or undesired events that may lead to falls. Accidents do occur and therefore we have to deal with them. In this case, we try to determine the problems in the site that caused the implemented safety to fail, and then take adequate preventive measures to avoid the reoccurrence of the accident. There are two problems with this approach: (1) accidents are rare events and it is possible that a system with a hazardous environment will operate without accidents; and (2) accidents usually bring with them unwanted events or consequences, such as injuries or deaths. Obviously, the second approach is more desirable given that it uses a proactive approach to deal with potential hazards (i.e., identify the potential hazard, study the best ways to eliminate or avoid it, and implement those methods before the hazard causes a fall).
As discussed in the previous sections, falls are the main cause of injuries and deaths in construction. Therefore, the main objective of this research project is to develop a tool containing knowledge about unintentional falls in the construction industry, including falls from higher elevation, falls from the same level, and slips (not falls). This tool incorporates all engineering aspects, and other aspects pertinent to the engineering control system (e.g., procedural, behavioral, and social aspects).

The system may be used to investigate construction accidents, evaluate the factors that may contribute to construction falls, and train users on fall hazards and ways to avoid them. In this project, we limit the use of SAFETY FIRST to construction falls. When implemented, SAFETY FIRST is expected to accomplish the following:

1. To provide an expert system with which to investigate a construction fall that has already occurred. The expert system identifies a particular event or combination of events that are the likely cause of the accident and explains how and why the fall has occurred. In addition, the system provides recommendations on how to avoid this accident in the future.

2. To provide an expert system to evaluate the existing fall protection in a construction site. The system determines if the fall protection devices used to prevent falls from a given elevated component are adequate (according to OSHA standards and experts' input). The system serves as a means to warn users of potential fall hazards and to suggest applicable precautions to eliminate or avoid these hazards. The system may also be used to determine the proper safety cautions and devices to be used given certain site and work conditions.
3. To provide an expert system tool that can be used at the design and planning stages of a construction project to try to eliminate potential fall hazards at the early stages of the project. The system will identify potential problem areas and provide recommendations to overcome them.

4. To provide a computer-based training tool to educate workers on the events that may lead to construction falls, the safety procedures to avoid falls, the proper way to implement a fall safety program, the proper way to install safety devices in order to both prevent falls and ensure compliance with OSHA standards, and other knowledge related to fall safety. The training program will also maintain records on each worker's performance. These records will be available for access by both management and OSHA inspectors.

In order to systematically analyze the construction system and identify the potential hazards that may cause falls and slips, a fault tree analysis technique is used to identify all the possible events that may lead to a fall accident in the construction environment. The relations among the events depicted in the fault tree are later used in the development of the expert system modules of the system, especially the investigation and evaluation modules. Further, this knowledge will be part of the training module of the system.

In addition to the computer tool which can be used to tackle specific aspects of the fall safety process (i.e., investigation, evaluation, design and planning, and training), it is important to recognize that this kind of tool will be best used in a company whose environment already promotes safety as a major priority. In order to implement the recommendations of the system, site management must have the resources and top
management support to do so. Therefore, as a part of this study, we include a discussion of the elements that a sound, long term safety program should have in order to be successful (see Chapter 2).

It is expected that the system developed will play an important role in minimizing construction falls, improving safety, and investigating the causes of fall accidents in the field. In addition, we expect that SAFETY FIRST will be used by private companies, such as general contractors, subcontractors, safety consultants, and other safety-related companies as a tool to identify conditions that are potentially hazardous to workers and to understand that safety pays; and by government agencies, such as OSHA and BWC to investigate the causes of construction fall accidents and to train their safety inspectors; and by academic and safety institutions to train construction students so they can appreciate and simulate the often dangerous conditions of construction operations and the pertinent safety measures to be implemented to prevent fall hazards.

1.8 Scope and Limitations

As discussed in the previous section, for this study we performed a systems analysis (i.e., fault tree) to determine the potential causes that may contribute to falls from the same level and higher elevations, and slips. In order to study the causes of falls from higher elevations, we had to determine which surfaces or structural components were more significant (i.e., where most of the construction falls had occurred). These components were selected based on available statistics regarding construction falls and expert’s knowledge.
In a study of construction fatalities between 1985 and 1989, the Occupational Safety and Health Administration [OSHA 1990] found that the locations and activities from which most fall-related fatalities occurred are roofs (26 percent), scaffolds (19 percent), and steel erection (11 percent). Other locations from which a significant number of fatalities due to falls occurred, include: floor openings (6 percent), ladders (6 percent), and open sided floors (4 percent). Figure 1.6 shows the distribution of these fatalities according to their location or activity.

![Pie chart showing the distribution of fatalities due to falls](image)

Figure 1.6: Locations and Activities involving fatalities due to falls [OSHA 1990]

In 1994, Culver and Connolly performed a similar study of construction fatality data in the OSHA database. They examined 1954 fatalities (33 percent) occurring between 1985 and 1993 in the construction industry and found a similar distribution as to the elevated locations from which fall fatalities occurred (Figure 1.7)
Figure 1.7: Locations and Activities involving fatalities due to falls

[Culvert and Connolly 1994]

Based on these statistics, the following elevated components were selected to be studied: roofs, form scaffoldings, steel beams, floor openings, floor edges, ladders, wall openings, and tops of walls. There are six major types of access scaffoldings from which falls could occur: form, tube and coupler, suspended, wood pole, tubular welded, and mobile scaffoldings. All of them are equally significant. However, an analysis of the potential causes of falls from these components must take into account causes related to the structure collapse, such analysis often requires structural analysis of each of the structures support components. That kind of analysis is beyond the scope of this study; however, in order to illustrate the analysis process for such structures, a form scaffold was selected as one of the elevated components to be studied. The last two elevated components (i.e., wall openings and top of walls) were selected based on expert’s recommendations. In addition, it should be noted that the focus of this study is on falls that occur during the construction of vertical structures like residential houses and
commercial buildings. Falls into trenches and falls during bridge construction are beyond the scope of this study.

Numerous factors may contribute to the occurrence of a construction fall. These factors vary depending on the components from which falls originate, the construction operation being performed, the general safety practices used in the construction site (e.g., housekeeping and use of personal protective equipment), the safety devices used to prevent falls, the condition of the workers, and so forth. In this study, the scope is limited to causes of falls directly affecting the worker: enabling causes (e.g., worker health, worker drunk), triggering causes (e.g., impact from an equipment), and support-related causes (e.g., due to working structure collapse or conditions on working structure that may cause slips or trips). Furthermore, the study also incorporates the potential causes related to the general safety problems and fall protection problems.

Regarding the support-related causes of falls, the study assumes that the collapse of the support structure, if it occurs, is a main cause of a fall. However, for permanent structures, such as floors, roofs, top of walls, and even steel beams, such failures are a rare occurrence and the determination of the causes of such collapse often requires a detailed structural analysis. Therefore, for these structures, this study limits its scope to identifying the specific support component whose failure caused the structure to collapse and the general cause of its failure (i.e., enabling, triggering, or support-related). On the other hand, for portable ladders and scaffolding structures, the collapse of the support structure plays a more important role in fall accidents. In the United States, a study of accidental construction injuries and deaths by Culver and Connolly [1994] concluded that about 35
percent of the scaffold fall fatalities were due to equipment failure, such as collapse of the scaffold, defective planking, or a failed suspension system. The same conditions hold true for falls from portable ladders; although they usually result in worker injuries (i.e., not deaths). As a result, the potential causes of such failures are analyzed in more detail. As discussed above, this study only analyses form scaffolds; however, we believe that the problems that may cause such structure collapse could apply to other scaffolding structures collapse (e.g., the use of planks that are not scaffold grade, omission of bracings, and missing bolts).

The knowledge identified through the fault tree analysis of falls from the same level, the eight elevated components, and slips was used to develop decision structures and incorporate them into the knowledge base of the investigation module of the program. Further, with some modifications this knowledge was also incorporated in the evaluation module of the program; however, in this module the focus is on evaluation of the site conditions and fall protection of elevated components. These are the components from which most fatalities due to falls occur. A study of construction fall accidents between 1984 and 1988 by the United States Corp. of Engineers [OSHA 1992] found that sixty percent of the fatalities caused by falls started at elevations higher than 30 feet, ten percent from heights between 21 and 30 feet, twenty percent from heights between 11 and 20 feet, and ten percent from heights between 6 and 10 feet. No fatalities occurred at heights lower than 6 feet. Further, the knowledge incorporated into the design and planning module of the program is based on a review of literature and expert's opinions. Finally, the training module organizes and incorporates all of this knowledge into a program to train
workers in fall protection. The methodologies used to develop each of the program modules and other limitations related to the program development are discussed in the corresponding chapters.

1.9 Organization

This report is made up of eleven chapters comprising the research topics of this study. Chapter 1 consists of a general introduction of the motivation behind the study, objectives, scope and limitations, and benefits of this research. Chapter 2 provides a discussion of the researcher’s site visits and the general and safety specific tasks accomplished. As a result of these visits, an overall outline of the elements a safety program should have was developed and discussed in this chapter. Chapter 3 provides a background discussion about accident prevention, accident causality models and fault tree analysis. The fault tree structures developed for this research project are discussed on Chapter 4, together with a discussion of the potential causes of falls and slips in construction. Chapter 5 presents a discussion of the expert system developed to investigate falls and slips, including a discussion on the development tasks used to develop the system. The expert system model developed to assess current the safety conditions in the site with respect to fall protection is discussed in Chapter 6. The next chapter (Chapter 7) provides a discussion of design and planning considerations to be considered in order to prevent the occurrence of fall accidents in the future. This chapter also presents the expert system developed to accommodate this knowledge. Chapters 8 and 9 discusse the system development and system evaluation tasks for the expert system modules of SAFETY
FIRST. Chapter 10 includes a discussion of all steps in the development of the computer based training module of the system. This module has two branches: the first to train users in fall safety and the safety program and the second to maintain user training records and allow management access to them. Finally, Chapter 11 contains the summary, conclusions, and recommendations for future studies.
CHAPTER 2
BUILDING A FRAMEWORK FOR A SAFETY PROGRAM

2.1 Introduction

In order to increase the student's knowledge and experience about the different parties involved in construction processes, their interaction, and the different environments, equipment and operations required for unique construction jobs, the general committee members advised the author to visit about 20 companies involved in the construction industry, spending about a week at each company.

The visits to the contracting companies had two main objectives: to gain practical construction experience and to perform an assessment of the safety practices currently used in the industry. In the first part of the practice, the focus was on getting the student valuable exposure to the industry. The student worked alongside engineers, project managers, or site superintendents who acted as the student's mentors and helped him understand the decisions, activities, problems, and solutions involved in the jobs they were running at the time of the visit. In exchange, the student contributed his time and effort in whichever way was deemed adequate by the mentor. In the second part of the practice, the student worked alongside the people in charge of handling safety matters in construction sites (i.e., project managers, safety managers, and safety consultants).
As a result of this program, a total of 16 companies involved in the construction industry were visited. These companies encompassed four different parties in the construction industry: three engineering/design firms, ten general contracting firms, one construction managing firm, and two safety consultant firms. Some of the general contracting firms listed above also acted as subcontractors or construction managers for certain jobs.

2.2 General Practice

For the first part of the practice and training, the author gained a better understanding of the industry's construction practices and the managerial knowledge required to implement them. For example, the reasons behind certain managerial decisions, the functions and responsibilities of the parties involved in the construction process (e.g., estimator, scheduler, foreman, superintendent, project manager, engineer, architect, etc.). The following are a few of the tasks performed during these visits:

- Getting familiar with some of the projects the companies were involved in, including remodeling and new construction work, as well as vertical (i.e., building) and horizontal (i.e., bridge and road) construction projects. The student performed a combination of office and field work.

- Reviewing project plans and identifying submittal items to be obtained from subcontractors and material suppliers for architect or owner approval.

- Contacting subcontractors working on the project and getting submittals from them (i.e., price quotes, samples, warranties, etc.).
- Verifying that submitted items complied with the project's plan and specifications. Several materials were found to be outside the limits delineated by the specs.

- Developing activity schedules for various project sections. A large part of the time was spent reviewing the plans and specifications for the project and getting familiar with Suretrack and Primavera scheduling packages. The level of detail used on the earlier schedules was limited. More detailed schedules were developed later on with help from the project's superintendent or manager.

- Getting familiar with Expedition, an add-on computer program used concurrently to Primavera Project Planner, which allows the contractor to keep records on work completed, change orders, correspondence with subcontractors, and payments due.

- Attending negotiation meetings between project managers and subcontractors to discuss their project bid.

- Attending progress meetings with various owners and architects. The project manager gave an update of the work completed on the site, the status of changes wanted by the owner, the status of request for information (RFI) forms (i.e., clarifications or information required by the contractor from the owner or architect in order to continue their work), and other problems encountered (e.g., failure to secure EPA permits required to build in a wetland area).

- Attending a monthly progress and budget report meeting. In the progress meeting, the project managers discussed the status of their projects, including activities being performed, expected problems, change orders, delays, and expected completion date. In the budget meeting, each project manager was expected to make a prediction of the
project status in terms of expenditures and expected profits or losses at the completion date.

- Attending a coordination and scheduling meeting between a general contractor or construction manager and the project's subcontractors. In the meeting, problems encountered by subcontractors were discussed, work was scheduled to minimize conflict areas among trades and give priority to areas critical to the project completion, and resource sharing was discussed among subcontractors (e.g., a painter will use the scaffolding erected for a mason).

- Verifying measurements in the field, reviewing work quality, keeping track of daily work completed, and keeping track of the amount of labor in the site by both the contractor and subcontractors.

- Leveling and laying out floor walls and duct (e.g., HVAC) locations, according to the project's blueprints.

- Assisting a site superintendent to read and interpret blueprints. Missing information was extrapolated from given information and field measurements. Conflicting measurements and some missing information required contacting the architect for clarification.

- Updating the project blueprints in the field according to the changes authorized by the architect via RFI forms. These as built blueprints will be submitted to the owner at the project completion.
2.3 Safety Specific Practice

In the second part of the program, the author gained a better understanding about the current safety practices in the construction industry. For the bulk of the visits, the student worked alongside safety managers from two general contracting companies, people in charge of safety matters in four contracting companies, and safety consultants from two safety oriented consulting companies. The following are a few of the safety-related tasks performed by the author during these visits:

- Attending toolbox safety meetings. These weekly safety meetings try to reinforce safe practices in a specific topic (i.e., use of fall arrest systems while working on roofs). They were performed in four of the companies visited. The meetings lasted between 15 to 20 minutes and their objective was to strengthen in the workers’ mind the companies’ commitment to safe behavior and practices and to refresh knowledge already given during previous and more detailed training.

- Attending and participating on site assessment visits with project or safety managers from three companies. Depending on the contractor, these visits occur every two weeks or every month. During the visit, the manager evaluates the safety conditions in the construction site and the behavior of workers on it. The ever changing nature of construction projects implies that new safety challenges arise as they progress. The safety managers help to foresee and discuss potential safety problems on upcoming work and detect and overcome current safety problems. If a safety manager is in charge of safety, he or she cannot be on the site at all the time. Usually, he or she has the responsibility for more than one construction site’s safety. If a project manager is in
charge of safety, he or she has other responsibilities to deal with. The main burden of safety should be carried by the people in the field. Therefore, safety managers should also try to educate both site managers and workers to detect and overcome these hazards. Safety managers are also in charge of keeping written records on all safety related matters.

- Attending and participating in on-site assessment visits with safety consultants. Here, the objective of the visit was to perform hazard identification and to delineate the safety policies for the client company, depending on the level of commitment from management. To delineate these policies, current OSHA and ANSI standards for the identified hazards were reviewed in order to determine the training and equipment required. Finally, given the resources available (i.e., human and financial) and the resource needs, the consultants determined the safety policies and how to incorporate them into the company’s practices.

- Reviewing the training videos used by one of the contractors in fall protection training. The videos are technically sound as far as compliance with OSHA standards; however, they over simplify the problems involved, use terminology which may not be clear to the worker, and lack interactivity (e.g., trainee cannot ask questions).

In addition to these tasks, during the site visits, part of the focus was on reviewing the companies’ safety programs (if existent) and site safety practices, including: implementation, enforcement, and effectiveness. From these visits, it was found that the three engineering consulting firms had checks to guarantee the safety of the designed structure; however, in terms of worker’s safety during construction stages, their
involvement was null. Currently, the burden of worker’s safety falls on the contractors.

The design firm involvement on the site is limited to answering RFI’s from contractors and subcontractors and overseeing that the built structure complies with the designs and specifications. As for the contractors and subcontractors visited, two of the major contractors were found to have above average safety programs in terms of planning and implementation in the site (i.e., go above and beyond what is required by OSHA). Six companies were found to have written safety programs which complied with OSHA standards. In terms of implementation, these safety rules were followed to the letter for the most part; however, in certain circumstances, site managers would agree to by-pass some of these rules (e.g., safety equipment was not available, equipment set up time was too long compared with expected hazard exposure, etc.). Three contractors were found to have no written safety program in place; however, as the contractors in the previous group, they attempted to comply with most OSHA standards, given the availability of resources. Certain exposures to hazards are deemed to be part of the job. Finally, two of the companies visited were found to have no safety program in place and their safety practices in the site were found to be risk-prone (i.e., there was no attempt to maintain a minimum level of safety on the sites). Based on the study of these companies safety programs and practices (i.e., both successful and deficient), the next section presents a discussion of the elements found to be essential to the implementation of a safety program.
2.4 Elements for a Successful Safety Program

A safety program should be the statement of the company's commitment to providing workers a safe working environment where no accidents, illnesses, or injuries are justifiable. The program should be approved by the highest ranking officer in the company and it should spell out the policies, processes, and procedures of the company towards safety. It should spell out the responsibilities of all parties in the company towards the safety program implementation. Further, it should delineate values and behaviors expected from employees by the company. These values promote a safety culture where unsafe practices are not tolerated. Safety procedures must be followed at all times by everyone (i.e., safety is as important as production and profits).

A safety manual should indicate the potential hazards the contractor will be exposed to, the procedures to overcome these hazards (e.g., eliminate them, guard them), the safety equipment to be used, and the training required. This manual will act as a reference for all employees of the company in matters of safety. The manual may focus on complying with OSHA standards or may go beyond these minimum standards and establish more strict safety policies for the company.

In order to implement a sound safety program, various elements are essential. These elements were obtained based on a qualitative study of the safety programs of the various contracting companies visited and their success or failure to implement their various policies. Further, information obtained from discussions with experts from the Occupational Safety and Health Administration (OSHA) and the Bureau of Workers Compensation (BWC), and from existent literature on the field of construction safety
contributed to determine these elements. In some cases, certain elements included in this list were not extensively used in any of the companies visited, but were deemed potentially important elements which could be used to further improve safety programs in the site. For example, very few contractors attempt to use performance assessment methods to evaluate the effectiveness or lack effectiveness of their safety program. However, one of the best ways to improve a safety program is to constantly review it and improve it, as needed.

2.4.1 Hazard Identification

Not all safety programs and their requirements fit all companies. In fact, the nature of the safety program depends on the area of expertise within which the contractor is working (e.g., underground excavation, electrical work, general contractor, etc.). The hazards to which a contractor's workers are exposed depend on their area of work. For example, a general contractor performing all of his or her work may be exposed to more hazards than an electrical subcontractor. Therefore, the first step in the development of a safety policy is to identify the hazards and conditions to guard against.

Once these hazards have been identified, the next step is to learn as much as possible about them, including their characteristics (e.g., the severity of their consequences -- death vs. injury), worker behaviors that may intensify or make these hazards more risky, and the potential ways in which one can reduce the significance or eliminate these hazards. This knowledge may be acquired from technical publications, codes, or the experiences of other contractors.
2.4.2 Implementation

Once the knowledge about the hazards has been obtained, the next step should be to implement a set of safety goals, policies, and procedures that will help overcome them. "For a (safety) program to be effective, it must be clear in its intent, and it must be uniformly applied to all company projects and personnel" [Hinze 1997]. The goals provide the primary safety objective of the safety program. This objective could be to reduce or avoid OSHA citations, to reduce or avoid litigation, to reduce the worker exposure to hazards, or to reduce or avoid worker injuries. Of these goals, the last two are probably the best, given that by reducing hazard exposures or injuries, the other two objectives (i.e., OSHA citations and litigation) will be taken care of. If the focus is on avoiding OSHA citations, depending on the level of scrutiny expected from OSHA inspectors, management may pay more or less attention to emphasizing safety standards. For example, management may pay less attention to compliance at remote and less likely to be inspected sites. If the focus is on avoiding litigation, management may gear its effort towards trying to shift blame (e.g., hold-harmless contract provisions), creating an atmosphere in which no one feels responsible for job-site safety [Hinze 1997].

A more specific statement of the company's commitment to safety is the mission statement. It is a general but powerful statement outlining the company's views on safety. For example, "We are fully committed to safety, and we integrate safety into all of our activities. Safety is our top priority. We will not compromise our safety philosophy to meet budgets, deadlines, or scope of work objectives or to achieve any other project goals. Our commitment to safety means we are committed to performing all our tasks in a
safe manner. That commitment to safe performance is mandated for all those employed by
our firm” [Hinze 1997].

The policies have the objective of connecting the safety program’s goal to the
safety procedures and activities outlined within it. The policies may state the scope of the
program’s application (e.g., for all construction activities within the site), the
responsibilities of all the parties within the safety program, and outline all the practices
that will be followed to ensure the safety program will be a success. For example,
frequency of training (e.g., safety meetings will be held every week), incentives and
punishment, and evaluation procedures (e.g., a complete a job hazard analysis will be held
each month).

Finally, the procedures spell out the specific activities and practices to achieve the
desired objectives. They outline the measures to be taken in order to avoid or overcome
site-specific hazards. For example, in order to prevent workers from falling through an
unprotected and elevated floor edge, a guardrail system should be erected on the edge.
Further, the program will outline the characteristics (i.e., height, strength, etc.) that the
guardrail should comply with in order to be effective. At the minimum, the contractor
should comply with the federal (i.e., OSHA), the state, and the local regulations.
However, in many cases, these are minimum standards; therefore, the owner may want to
implement its own safety guidelines.

These policies and procedures should be clear and enforceable. For example, one
of the construction companies visited had a rule that eye protection must be worn by all
workers and managers while on the site. The safety manager explained that the reason for
This policy was that for many construction operations workers required goggles in order to protect their eyes from debris generated. However, if the policy restricted the use of eye wear protection to workers performing certain operations, the policy would be harder to enforce (i.e., managers would have to determine whether or not the rule applies) and unclear to the workers (i.e., when to use eye wear?).

These policies should also be under the control of the company to enforce them for the benefit of its workers’ safety. However, the safety manager (if such position exists) should not be the only representative of the company promoting safety. Site management (i.e., superintendents, project managers, and foremen) and workers should play a role in promoting safety. Therefore, the safety program should make clear the responsibilities and rights of both the management and the workers.

Under the safety program “safety is an integral part of the organization and as such management must make it part of their every day responsibilities” [Hansen 1995]. Management needs to recognize that the worker is only one element in a system which includes the working environment, the safety equipment available, and policies and practices of the company, among other factors. Therefore, in order to prevent accidents all of these factors must be considered and controlled. Management plays an important role in implementing and enforcing these control measures. Among the rights and responsibilities of site managers are the following:

- They should be trained to know the hazards characteristics and procedures to overcome them. In order to provide leadership in safety matters, they need to understand all
aspects related to the potential hazards. For example, what worker behaviors are risky and how to eliminate them.

- The managers should have access to the safety equipment required for the enforcement of the policies and procedures outlined in the safety program. In the previous example, all safety devices needed by the workers were available in the company’s trailer. However, had these devices not been available, it would have been impossible for the safety manager to enforce the safety program.

- They follow all safety rules while working in the site. They should lead by example and emphasize that there are no exceptions to following the company’s safety policies.

- They are willing and able (i.e., have the authority) to enforce all the policies under the safety program. No exceptions or excuses are made or allowed when it comes to safety matters. If, because of time constraint pressures, the manager allows or instructs a worker to perform a job in an unsafe but faster manner, the message to the worker is that safety can be disposed of under certain circumstances; and he or she is likely to find other circumstances which in his or her mind warrant ignoring safety. For example, two of the contractors visited have a policy of immediate dismissal for use of illegal drugs. In both cases, the policy is enforced to the letter, meaning that no excuses are allowed for workers who miss (e.g., worker could not attend the test due to his or her work responsibilities) drug tests. They are not allowed on the site until they take the test. If they fail the test, they are dismissed from the company, regardless of the company’s need for the worker’s skills. Further, in order to protect their workers from accidents caused from subcontractor workers’ mishaps, the companies also have policies requiring
subcontractor’s labor working on their site to pass a drug test before being allowed in the site.

- The managers should provide workers with immediate feedback regarding unsafe behaviors, including explanations as to why certain behaviors are not acceptable and safer alternatives to the worker’s current behavior. For example, during the student’s visit to one of the sites, workers were moving materials into the fifth floor of a ten story building through a floor edge. To do this, the wire ropes that acted as top and middle rails and protected workers from falling from the floor edge were temporarily removed. As a consequence, in order to grab the materials from the crane and pull them into the floor, the workers were operating near an unprotected floor edge. In this case, given the immediate danger to the workers’ lives, once he noticed the situation, the project manager instructed workers to stop their work and get harnesses to tie up.

- They analyze the job site, recognize potential hazards, and implement counter-measures to ensure safe working conditions (i.e., engineer out or reduce the hazard).

- They should create a working environment where workers are involved in enforcing and implementing safety. In order to find and eliminate problems, workers’ input should be encouraged. The objective is to eliminate safety problems; therefore, the response to the identified problems should be promptly and effectively eliminate them, without assigning blame for their occurrence.

- Finally, site managers are responsible for investigating accidents and near-miss accidents immediately after they have occurred. Timely investigation of these accidents is likely to result in the identification of potential problems which may have not been considered
during the safety program’s development, allowing the manager to provide feedback for
the safety program’s improvement.

Workers are entitled to have a safe environment where no risks to their health
should be expected. However, in order to accomplish that objective, they should be
actively involved in the efforts to prevent accidents. They cannot rely solely on the
management efforts (not all hazards can be foreseen by standards). Therefore, they should
be trained to recognize hazards. Further, under the safety program, their input in hazard
prevention should be encouraged. Among the workers’ rights and responsibilities, are the
following:

- They are trained to recognize and react properly to site hazards. They should have
decision making power to stop potentially dangerous situations on the site if no
management representative is in place to make those decisions.
- They have all safety equipment required to perform the job safely available to them.
- They follow the safety program and understand the consequences of their failure to do
so. For example, in one of the contracting companies visited, a worker performing a job
in a scissor lift movable scaffold, while he went down to get a tool in the floor, left the
equipment running with the hand brake on. The brakes in the equipment malfunctioned
and the lift displaced, hitting a scaffolding structure next to it. The impact of the lift on
the scaffold caused a worker on it to lose his balance and fall. The worker broke his arm
as a result of the accident. This accident could have been avoided, if the worker had
been aware of and had followed safety practices which stated that the movable scaffold
must be turned off if no worker is operating it. Further, the worker, whose failure to
turn off the equipment caused the accident, was suspended for three days (i.e., first offense) as stated in the company’s safety program.

- They strive to achieve safe work practices (i.e., follow safety procedures even while outside supervision) and provide feedback to management about unsafe practices. For example, reporting near-miss accidents so that they can be studied and their causes identified and eliminated.

- They provide feedback to coworkers about unsafe behavior and accident prone conditions.

All employees in the company should be aware of these rights and responsibilities and should be encouraged to share the responsibility for safety. In order to achieve such an objective, management should promote an error-free atmosphere to prevent finger pointing when errors occur and obstacles to employee management communication must be removed. However, each party in the company should be accountable to abide by the safety program and its rules. Therefore, copies of the program should be given and explained to all of them. Further, copies should be available for consulting at all job sites.

Finally, the responsibilities and rights of managers and workers described above should not change if the contracting company has a safety officer on its staff. In most cases the officer will have to monitor the various construction sites the company is working on. He or she cannot be present in one site one hundred percent of the time. Therefore, the safety officer cannot be the sole party responsible for implementing and enforcing the safety program. Instead, he or she should focus on the following:

- Providing leadership on safety related matters.
• Providing or procuring training.
• Setting an example while at the site by following all safety rules
• Recognizing workplace hazards and together with the site manager's assistance improving work site safety conditions
• Complying with government regulations
• Ensuring that all the policies in the safety program are followed
• Maintaining safety-related records
• Investigating accidents in the site, reviewing the findings, and providing recommendations to the site manager.

2.4.3 Enforcement and Accountability

The program should clearly state the consequences to both management and employees for safety failures. Management has to create an environment in which safety is given its due importance. Failure to do so could have serious consequences. In two of the contracting companies visited, one of the criteria used to rate project managers', superintendents' and foremen's performance (i.e., used for hiring and promoting them) is safety performance. The commitment of managers is essential for the safety program's success. In three of the site visits, it was found that contractors had soundly written safety programs; however, they did not translate into safe practices in the site because the superintendent and foremen did not make an effort to enforce them. This also gave workers the idea that safety is secondary.
Research in this area confirms these facts. For example, Sloat [1996] indicates that if the observable factors in the environment (e.g., warning signs, PPE, housekeeping style) and work procedures (e.g., safety meetings, inspections, work methods) are in conflict with the company's safety values (i.e., the safety rules behind the actions; e.g., principles, policies, goals, and standards) and assumptions (beliefs behind the values; for example, safety training will encourage safe behavior), the commitment of the workers to the safety program is weak. For example, if the underlying reason for toolbox meetings is to comply with the safety program by getting employees involved, getting their inputs and ideas regarding on-site safety, the level of involvement and commitment to it and the safety program will be significant. In contrast, if the underlying reason for the meeting is government requirements compliance, the employees will go through the motions, but their practices and beliefs are not likely to change.

Geller [1994, 1995] also supports the idea that safety should not be a priority but rather a value. He argues that priorities often change depending upon the situation and may be driven by factors such as productivity and profitability. In contrast, values remain constant. They are "deep seated personal beliefs that are never compromised ... Safety should be a value that employees bring to every job regardless of priorities or task requirements. It should be an unwritten rule (social norm), one followed regardless of the situation" [Geller 1994]. In order to promote safety as a value, the safety program should give workers the mental (i.e., knowledge) and physical (i.e., safety devices) tools to achieve the safety objectives. Further, it should create an environment that promotes the
active involvement of workers on safety (e.g., overseen their and their co-workers working conditions and acting whenever a situation requires them).

In the same manner, safety policies and procedures should be a part of the workers' job responsibilities and they should be accountable for safety violations. Because of these policies, workers expect to see some consequences coming to workers who behave in a risk prone manner. The safety program should outline the disciplinary actions that will be used in cases where workers at risk of injury do not change their behavior. The program should clearly spell out the situations where such actions will be applied. These rules and the reasons behind them should be clearly explained to the worker at the outset of his or her employment. Finally, the rules should be applied fairly and consistently. The lack of disciplinary response from management to certain situations may indicate to other workers that the contractor is not committed to the safety program and thus send an unspoken negative signal.

2.4.4 Incentives

In some cases, in order to encourage positive behavior from workers, contractors also provide incentives (e.g., rewards, raises, or promotions) the worker may earn for working safely, for reporting safety problems in the site, from reporting near-miss accidents, or for having a clean safety record for a certain period of time. These incentives as a part of a structured safety program, can help in improving the safety behavior of both managers and workers.
McAffe and Winn summarize findings from 24 studies on the effectiveness of positive reinforcement and incentives in the workplace. They found that the use of positive reinforcement or incentives "removes the unwanted side effects associated with discipline and the use of penalties; it increases the employees' job satisfaction; it enhances the relationship between the supervisor and employees; (and) it increases the probability of safe behavior rather than reducing the probability of unsafe behavior" [McAffe and Winn 1989]. Further, most studies found that in most cases incentives and feedback helped improve safety conditions or reduce accidents, at least in the short run.

In the minds of many workers (i.e., those not really aware of the potential consequences of accidents) safety measures require too much time and effort to setup, given that "the unpleasant consequences that safe behaviors avoid rarely occur" [Geller 1992]. A well implemented reward system can help counter balance this type of attitude and support safe behavior. However, according to Geller, many incentive programs fall short of the objective (i.e., encourage safe behavior and practices) by narrowly focusing on reaching a certain number of safe work days. The problem with this method is that it inhibits incident reporting as workers may feel peer pressure not to report incidents in order to avoid losing the award. This may also create a false sense of security as the number of actual incidents has not decreased; though the number of reported incidents has. Geller gives the following guidelines to developing incentive programs:

- The incentives should be given for specific desired behaviors.
- The behaviors to achieve a reward should be specified and perceived as achievable. For example, attending safety meetings, performing job safety analysis write up, conducting
periodic audits of equipment and environmental conditions, certain specific work practices.

- Groups should not be penalized (lose reward) for individual failures.
- It is better for many participants to receive small rewards than for one person to receive a big one.
- Progress should be systematically monitored and posted for all participants.
- The late reporting of an injury is penalized with loss of credit.

Research indicates that incentives alone cannot replace a safety program. They can arouse short-term interest in safety and as a consequence improve compliance with safety rules. However, in order to achieve long term objectives, these incentives should be part of a safety program. The safety program will facilitate the development of an environment where safety is a priority. Further, it will outline the practices that will help control or eliminate the hazards in the site. Finally, the use of incentives should be complemented with training that educates the workers as to the reasons certain safety behavior is being rewarded by the company.

2.4.5 Training

The safety goals, policies, and procedures of the company should also be written, visible, and understood by all affected by them. Training programs by the company should fulfill the role of educating both managers and workers as to the hazards they are exposed to, the procedures implemented to control them, and the impact of each party on the success of the safety program.
According to Geller [1994, 1995] and Spigener [1995], worker behavior is affected by his or her beliefs, values, and perceptions of the realities in the work site. Unfortunately, "when it comes to occupational safety, the human learning cycle is plagued by a paradox that sets people up for injury. That paradox is this: individual experience does not match group risk ... That means that even in the case of a critical at-risk behavior, an individual may perform it a thousand times with no ill effect -- the outcome is unpredictable. However, when hundreds of workers each perform that at-risk behavior thousands of times, there is no unpredictability about the outcome -- someone is going to get hurt" [Spigener 1995]. For example, in determining whether to use fall protective equipment or PPE, the worker will use his or her beliefs as to his susceptibility to the hazard, the seriousness of the potential accident outcome, the expected effectiveness of the preventive device, and the additional effort associated with the new safety practice/device. Unfortunately, these factors are influenced by the preceding experiences of the worker. Therefore, if the worker behaved unsafely without problems, the lack of negative consequences from previous behavior may reinforce negative practices. Training may be crucial to the success of the safety by focusing the worker's attention on the certainty that unless they change their behavior and develop safe habits, accidents are likely to happen.

The objective of the training program is to make managers and workers more educated regarding site hazards, unsafe procedures, and their consequences, and correspondingly change their behavior for the better (i.e., reduce the number of unsafe behavior instances). Research indicates that workers will be willing to change the way they
do their work when they realize: "(1) they are capable of change, even if it causes discomfort at first; and (2) the 'new way' of doing things has real long-term benefits" [Baldwin 1991]. By educating both managers and workers, they are able to actively participate in evaluating and improving the safety program and its implementation on the site. A detailed discussion of the current training practices in the construction industry and the future needs in this area is included in the chapter discussing the training module of the SAFETY FIRST program.

2.4.6 Performance Assessment

In order to determine the efficiency of the safety program, management must have a method to gauge progress or lack thereof. The objective of the performance assessment is to identify areas for which the safety program has been successful and areas where improvement is still possible (e.g., hazards not considered in the safety program procedures, hazards for which current safety procedures are falling short of the objective, or policies not implemented in the site). Not all hazards can be foreseen or predicted. Construction working environments and conditions are continuously changing or evolving. Therefore, the safety program should also improve continuously. Carder provides the following guidelines regarding the assessment method:

- It "must be valid. It must facilitate understanding of the underlying system. Validity must be evaluated by the measure's ability to predict future loss, or by its ability to enable effective system improvement" [Carder 1994].
• It "must be reliable. Essentially, measurement must be repeatable. The method must be specified so that other can follow the same steps and obtain a similar result" [Carder 1994].

• It "must not, in and of itself, interfere with improvement efforts. For example, the use of incident rates as a criterion to evaluate employees may increase the potential that some incidents will not be reported" [Carder 1994].

Further, Carder emphasizes that in order to get a better safety measurement of the strengths and weaknesses of the program, the best strategy is to use more than one measurement method. The following are some of the assessment methods that can be used to measure safety performance in the site:

1. Safety problems encountered by project manager. If the manager maintains records regarding the safety problems encountered or brought to his or her attention during the performance of the job, he or she will be able to see if the trend is towards a safer site or vice versa. For example, if the number of safety problems encountered this month is smaller than those in the previous months, this may be an indication that the safety on the site has improved

2. Safety Audits. It is an announced or unannounced visit where the safety manager performs a visual inspection of the site's safety conditions. This is not a fault finding procedure, but rather a tool to diagnose the effectiveness of the safety program and to improve safety conditions in the site. The objective of the visit is to detect potential hazards and assess the potential consequences associated with them. If the potential consequences associated with the hazard are serious, preventive action must be taken
immediately or worker access to the hazardous area must be prevented until appropriate measures are taken.

Announced and periodic visits allow the safety manager to observe environment and workers behaving according to specified standards and procedures. Unannounced visits allow him to determine the level of compliance with the safety measures specified on the safety program [Hansen 1995]. As a consequence of the audit, the safety manager and the site manager (i.e., project manager, superintendent, or foreman) will identify potential hazards, select measures to eliminate or minimize their consequences, and monitor their implementation.

If detailed records are kept as to the problems found on each audit visit and the recommendations for improvement, these audits can be used to monitor progress on the site safety. For example, they can be used to determine if the number of violations or hazards has increased or decreased over time, if the problems identified have been dealt with in a timely fashion, or if they have been found repeatedly.

3. Accident Rates. In a stable system, they have predictive validity. For example, an accident rate decrease may indicate a safety improvement. However, they leave out incidents in which no injuries occurred (i.e., they are not recorded). Further, if management and workers in the site know they are used to measure improvement, certain minor accidents may not be reported.

4. Accident and Near-miss Investigations. An accident may reveal underlying system problems that need correction. Data from various accidents/incidents will give information about problems that may be common to these accidents. These problems
may have not been as obvious when observing the individual incidents separately. Effective accident investigations are prompt and comprehensive. The accident site should be investigated while the environmental conditions on the accident site are unmodified and the facts of the accident are still fresh on the minds of the injured worker and eye witnesses. They should leave a record of the root problem that caused the accident. These records may allow the safety officer to identify potential weak links in the company's safety program.

Accident investigation data is limited by the number of accidents occurring at the site. However, "near-misses occur more frequently than accidents" [Carder 1994] and their analysis can also reveal problems that may also lead to accidents. Near-miss accidents may be a symptom of a major accident waiting to happen. Therefore, they should also be recorded and investigated. These investigations allow the managers to identify weak areas in the safety program and thus will allow the company to focus their efforts on correcting them.

5. Safety Sampling. This involves a systematic observation of the workers performing their work at the job site in order to determine the unsafe acts being committed and how often they are occurring. It helps identify weak areas in the safety program or its implementation [Carder 1994]. For the success of the sampling, the worker should not be aware he or she is being observed, otherwise his or her behavior may change (e.g., become more safety conscious) and the objective will not be achieved.

6. Employee Safety Surveys. This consists of interviews, questionnaires, and meetings given to the workers in order to gather information about their opinion of the safety
program and its strengths and weaknesses. These surveys have the advantage of getting workers involved in site safety, raising their awareness about safety, promoting open communication between management and workers, reinforcing the idea that safety is an important management consideration, and revealing aspects of equipment operation, procedures, or policies that inadvertently encourage employees to violate safety rules (e.g., if employees indicate that within their job tasks they are asked to perform unsafe acts, a weak point in the program's implementation is found) [Carder 1994].

7. The Experience Modification Rate (EMR). As discussed on Chapter 1, the EMR is the component of the workers' compensation cost that modifies the insurance rate the contractor will pay according to the contractor's accident history. This rate (EMR) is calculated separately for each contractor based on his or her individual losses. It increases the premiums for contractors with more claims than the average and lowers it for contractors with lower than average claims. Therefore, this rate can be used to track the annual progress of the contractor regarding safety matters. A EMR rate lower than the one the previous year will indicate that the contractor has had a better accident history (i.e., less accidents). The opposite also holds true a higher EMR rate would indicate a worst accident history. However, in order to use this rate to track safety progress, the contractor must understand the following factors:

(1) the time period used in the EMR calculations for a given year is the three years prior to the immediate past year (i.e., the most recent year claims are not used as some claims may not be settled). Therefore, a company that achieves improved safety
performance in a year has to wait at least two years before the improvement reflects in a better EMR record and even then the improvement may not be as great given that the record from the two previous years of poor safety may still drive the rate. This also implies that in order to see the full improvement resulting from a safety program, the contractor has to wait for at least four years. This requires long term planning and commitment.

(2) "the formula (to compute the EMR) includes both frequency and severity of accidents, but it counts frequency much more heavily. Thus, if a company has one very severe accident during a three year period with claims adding up to $30000, while a competitor with the same payroll in the same work classifications had 15 accidents with claims of $2000 each during the same three years, the competitor’s EMR would be higher" [Levitt and Samelson 1993]. Rating bureaus judge frequency of accidents more controllable than severity. This implies that all potential accident causes regardless of their perceived potential severity should be monitored and eliminated in order to reduce EMR costs.
CHAPTER 3

ACCIDENT PREVENTION AND CAUSE ANALYSIS MODELS

3.1 Accident Prevention

An accident can be defined as “any event which interrupts the normal work process caused by human, situational, and environmental factors, or any combination of these factors which may or may not result in personal injury, death, property damage and other undesired events— but which has the potential to do so” [Firenze 1978].

Accident prevention deals with the methods to control the occurrence of accidents. Heinrich et al. [1980] defined accident prevention as an integrated program or a series of coordinated activities directed to the control of unsafe worker performance, mechanical conditions, and working environment. They also stated that these control measures may be decided based on the knowledge and experience of the safety manager or by virtue of analyzing the system.

In order to avoid accident occurrences, the safety manager will focus his or her attention on the site hazards which alone or in combination may cause those accidents. A hazard is defined as “any existing or potential condition in the work place which, by itself or in combination with other variables, has the capacity to result in the unwanted effects of deaths, injuries, diseases, damages, and mission loss” [Firenze 1978]. Because hazards
deal with conditions that have the potential to cause harm but may not exist yet (i.e., not lead to an accident yet), usually the objective is to identify and control these hazards.

There are two potential approaches to hazard control. The first approach involves the investigation of accidents after they occur. In this case, we try to determine the problems that caused the implemented safety to fail, and then take adequate preventive measures to avoid the reoccurrence of the incident. There are two problems with this approach: (1) accidents are rare events and it is possible that a system with a hazardous environment will operate without accidents; and (2) accidents usually bring with them unwanted events or consequences, such as injuries or deaths. The second approach to hazard control tries to identify the undesired events in the system before they lead to accidents. To do this, the hazards that may lead to the unwanted accident need to be identified and studied to determine the best ways to avoid or eliminate them.

Currently, the updated model for accident prevention proposed by Heinrich et al. [1980] is one of the most accepted and used in the industry (Figure 3.1). The first item in the model is “the basic philosophy” which is related to the way we believe accidents occur (i.e., how and why). Several causality models have been proposed to address this matter. Some of these models are discussed in the next section. Next, the model outlines the fundamental steps to approach accident prevention: collecting data, analyzing data, selecting a remedy, applying the remedy, and monitoring the environment.
The first step in the preventive process is to collect data about the workers and the environment. The data may be collected from managers and workers through surveys and questionnaires, behavior observation and site inspection trips, accident investigations, accident records, and other sources. The analysis of this data, combined with the safety engineer’s experience, will allow him or her to identify the potential hazards that may lead
to accidents in the site and the potential ways in which these accidents may occur. Based on this knowledge, the next step is to select the appropriate remedy to avoid or eliminate those hazards. The remedy may eliminate the hazard altogether, reduce its significance, or reduce the likelihood of its occurrence. Thereafter, the selected remedy will be implemented. This step requires the active participation of the site management personnel and of the workers. Finally, the system (e.g., construction site) will be monitored to determine the success or failure of the implemented remedies. If the results are positive, the safety manager may focus on other areas needing improvement. If the results are not as expected, the manager needs to collect data again to determine the reasons for the remedy's failure and what can be done to improve the situation.

Finally, the accident prevention plan requires long and short term considerations. The short term approach focuses on dealing with and eliminating problems as they are detected in the site. The long term approach focuses on laying out the foundation for the detection and elimination of all potential safety problems in the site. This approach includes developing a safety program outlining the company's policies regarding construction safety; for example, training management and workers on safety related matters and their significance to the company's goals.

3.2 Accident Causality Models

In order to eliminate the occurrence of unwanted events, the way in which these events come into existence must be studied. This implies the identification of the factors (e.g., workers behavior and working environment) that cause these events and the way
they interact with each other. Once these factors are identified, the next step is to find and implement corrective measures to either eliminate unwanted events or reduce the consequences of such events.

Heinrich investigated the conditions and circumstances that cause industrial accidents. The accident sequence in this approach is represented as a series of dominos, as shown in Figure 3.2.

![Heinrich's Domino Theory](image)

Figure 3.2: Heinrich's Domino Theory

He argued that "the occurrence of an injury invariably results from a completed sequence of factors—the last one of these being the accident itself. The accident in turn is invariably caused or permitted directly by the unsafe act of a person and/or a mechanical or physical hazard" [Heinrich 1959]. This approach concentrates on an unsafe act or condition as responsible for the majority of accidents. Therefore, the removal of this act interrupts the sequence of dominos. These unsafe acts or conditions, according to Heinrich, were due to the social environment (i.e., help develop undesirable character traits), and ancestry (i.e., inherited or innate) factors combined with faults of individual workers. Therefore, Heinrich considered that the highest safety payoff comes from modifying the worker's behavior and/or eliminating unsafe conditions in the site (i.e., first
domino). He also concluded that management has "the best opportunity and ability to initiate the work prevention" [Heinrich 1959] and therefore it should assume the responsibility for it.

In addition to controlling worker motivation towards the job, management also controls the job site working conditions. With this in mind, several modern safety professionals have modified Heinrich's domino theory to take into account the importance of supervisory and management aspects in accident causation and prevention. The first updated domino sequence taking lack of management control into direct account was presented by Frank Bird Jr. [Heinrich et al. 1980] (Figure 3.3).

![Figure 3.3: Updated Domino Theory](image)

Bird introduced the idea of managerial error (i.e., loss control) into the causality sequence. According to him, the basic causes of the accident are related to the management's lack of control of the working environment. These basic causes relate to personal factors of the manager, such as lack of safety knowledge, improper motivation to work safely, physical or mental problems, and job factors (e.g., inadequate standards, wear and tear, and abnormal usage of resources). The immediate causes (i.e., unsafe acts and
conditions) are not the causes of accidents, but only the symptoms of managerial problems. Therefore, to prevent accidents, the causes of the accident must be related to the management system in the workplace and addressed at that level. The U.S. Army Institute of Administration has also developed an accident causation model to depict the causes of accidents and how they can be corrected (Figure 3.4).

![Figure 3.4: Army Causation and Countermeasure Model (Firenze 1978)](image)

All of the previous causality models are related to the original domino theory proposed by Heinrich and place emphasis on the role of management in safety. In addition to these, other causality models commonly used nowadays include behavior models, human factor models, and system models.

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"The first behavior theory historically was the notion of accident proneness" [Heinrich et al. 1980]. This theory assumes that certain personal traits make a person more likely to have an accident. The backers of the theory point to the fact that the majority of people have no accidents, while a very small percentage have multiple accidents. Although, the accident-proneness concept has historically been accepted, many laboratory and clinical studies have failed to find any common traits that may lead to accidents.

Another behavior theory proposed by Petersen has to do with the idea that worker's performance depends on his or her motivation and ability to perform [Heinrich et al. 1980]. Ability depends on selection (i.e., is the worker able to do the task) and training (i.e., does the worker know how to do it). Motivation depends on the company's policies and climate, the worker's personality and happiness with the job, job motivational factors (i.e., rewards), and the working peers. The worker's future performance also depends on the response (i.e., rewards or positive feedback) to the current performance and whether it met his or her expectations.

However, so many variables affect human behavior that it is very difficult to predict what motivates a worker. Douglas McGregor developed theories of human behavior that have been widely utilized by management in the industry. He presented two theories regarding human motivation [Marshall 1982]. The first one is that workers are motivated both by remuneration and other rewards and by the fear of disciplinary action. Therefore, if management wants the worker to perform in a safe manner, it must provide some tangible reward for doing so and some punishment for failing to do so. His second
theory is that workers are motivated by job satisfaction. Therefore, management should find ways to make the job satisfying to the workers. Nothing is more important than the workers’ attitude toward their work in determining their behavior and performance in the workplace.

Human factor theories indicate that accidents result from multiple causes, one of which is related to human error. The focus of these models is on the human response to negative or unusual situations on the work place (e.g., stress). These human errors could be caused by a task overload (i.e., a mismatch between the worker’s capacity and the work load he or she is subject to), incorrect responses due to incompatibility of the worker and the environment (e.g., inconsistencies in responses to hazards among managers and inconsistencies in policy implementations), and improper responses to certain situations (i.e., due to lack of training, risk taking attitude or accident proneness of the worker).

Newer systems models recognize that a system is made up of several components (e.g., management, worker, working environment, and equipment) and that an accident is usually caused by a complex mixture of factors affecting the various components and contributing to the final result. Firenze’s system model (Figure 3.5) is one of the most widely accepted [Firenze 1978]. Firenze states that each worker performs his or her job as a part of a man-machine system which includes the equipment and the environment where the work takes place. The match of all the system’s components (i.e., worker, equipment, and environment) is essential for success in accomplishing its task.
Furthermore, he states that in between the man-machine system and its task, there is a void corresponding to the process that takes place in order to accomplish the task (Figure 3.5 (a)). According to Firenze, this process is key to the system’s failure problem. First, the worker must make sound decisions in order to reach his or her objective. These decisions have certain risks associated with them. Second, the equipment in the system must function properly. This requires properly designed, selected, and maintained equipment. Third, the environment plays an important role in the equipment selection and use as well as the worker (e.g., weather conditions on the site).

![Diagram of Firenze's Systems Model](image)

Figure 3.5: Firenze's Systems Model
In order to make sound decisions and take calculated risks, the worker "must be aware of: (1) the job requirements; (2) his own capabilities and limitations relative to the job; (3) what will be gained if he attempts the task and succeeds; (4) the unfavorable consequences that will be suffered if the attempt fails; (5) what will be lost if the task is not attempted at all" [Firenze 1978]. The better the information the worker has, the better his decision and the more calculable the risk becomes. The poorer the information, the greater the opportunity for bad decisions and bad risks.

Therefore, Firenze points out that "a well-balanced hazard control program will, insofar as its workers population goes: (1) sensitize them to the types of hazards associated with their jobs; (2) instruct them how to mentally evaluate a hazard’s potential destructive effect and how to determine which ones are worth the risk and which ones are not; (3) demonstrate the ramifications of excessive risk by virtue of destructive potential and other adverse impact" [Firenze 1978].

Finally, Figure 3.5 (b) shows that "there are exceptions to the rule that a worker with full knowledge of his job will always make wise, calculated decisions" [Firenze 1978]. Certain variables (i.e., stressors) may affect the worker’s decision making ability clouding his or her judgment. These variables may be psychological, such as narcotics and alcohol; psychological, such as anxiety, aggressiveness, and fatigue; or physical, such as glare, temperature extremes, and low levels of illumination. Each of these variables by itself or in combination with other factors may lead workers to undesired risk taking.
situations. This is complicated by the fact that accidents are rare events and it is possible, by mere chance, for a worker to perform a task in a risky manner and yet complete it successfully.

In general, there are two types of analytical processes that can be used to analyze a system: inductive and deductive. Inductive analysis, such as Failure Mode and Effect Analysis (FMEA), Preliminary Hazard Analysis (PHA), and Fault Hazard Analysis (FHA), consists of reasoning from individual cases to general conclusions [NTIS 1981]. For a system failure analysis, inductive techniques would attempt to find out what would happen if some fault occurred in the system and what would be the possible failures that may result as the consequence. For example, if we take the fault "the worker is intoxicated at the construction site," there are several accidents that may result as a consequence (e.g., the worker may fall, be electrocuted, or be caught in between some equipment). Therefore, through this method we can evaluate the importance of avoiding the occurrence of certain events (faults) in the system.

The deductive method takes a different reasoning approach. It begins with a given failure mode (consequence) and ends with specific faults (i.e., causes) that may lead to it. In this case, we first consider a given type of an accident (e.g., worker fall) and then determine the specific faults (e.g., worker has health problems or worker is hit by something) that may cause or contribute to its occurrence. The fact that we can focus on one failure mode and determine how it can occur is the main reason why this type of analysis is used for this research. We are interested in identifying the causes that may lead
to a construction fall. Other failure (accident) modes, such as electric shock and caught-in-between some equipment, though important, are beyond the scope of this study.

3.3 Introduction to Fault Tree Analysis

The original fault tree analysis (FTA) is a deductive technique which seeks to identify all of the failure modes that can cause a system failure (top undesired event). In the *Fault Tree Handbook*, Roberts et al. [1981] defined a fault tree as a graphic model that shows “all the various parallel and sequential combinations of faults that will result in the occurrence of the pre-defined undesired event.” Hence, a fault tree can be constructed starting from the top undesired event (a fault or a failure) and then, by expanding it, reaching all possible faults that contribute to the occurrence of the top event. Through this method the analysts can identify potential “weak links” in the system and, visually observe how they interact with each other to cause the system’s failure.

The events contributing to the occurrence of the top undesired event are determined through the use of logic gates, which show the events or combination of events needed for the occurrence of a higher event. Given a specific gate, the higher event is the output of the gate and the lower events are the inputs to the gate. The relationship among the input events is defined by the type of gate used to connect them. There are several types of event and gate symbols. However, here, we will only discuss those used for this project. We will employ the symbols used in the *Fault Tree Handbook* published by the National Technical Information Service [Roberts et al. 1981].
Five types of gates are used in this study’s fault trees: OR, XOR, AND, INHIBIT, and TRANSFER gates (Figure 3.6). The OR gate indicates a situation in which if at least one of the input events occurs, then the output event happens. Next, the XOR (exclusive OR) gate is used if only one of the input events has to occur in order for the top output event to occur. The AND gate indicates a situation in which the output event occurs if all the input events occur at the same time. Further, the INHIBIT gate is used if a basic or primary event occurs simultaneously with a conditioning event, leading to the output event. In this case, the top event happens if a basic fault occurs in the presence of a conditioning event (restrictive condition). Finally, the TRANSFER gate allows the user to develop a fault tree while avoiding excessive use of symbols on one sheet. The tree can be broken into several branches depicted on different pages. In addition, this symbol precludes having to re-draw the branches of the tree that are identical in several places.

![Gates and transfer symbols](image)

**Figure 3.6: Gates and transfer symbols**

The symbols of events considered in this study are shown in Figure 3.7. The rectangle defines an “intermediate event,” which is a fault event resulting from the input causes acting through a logic gate. Next, the circle defines a “basic event,” which is a
cause that requires no further development. It is also referred to as a primary or generic failure [Barlow et al. 1975]. Further, the ellipse is used to represent a "conditioning event." which is an event that includes any restrictions or conditions to the INHIBIT gate. Finally, the diamond represents an event that is not developed further, or an "undeveloped event." These undeveloped events are those which are outside the scope of the study.

![Event symbols](image)

Figure 3.7: Event symbols

An example of a fault tree diagram is shown in Figure 3.8. As mentioned above, the analysis starts with the top undesired event, which is the final failure to be analyzed. Next, the events directly contributing to the occurrence of that top undesired event are identified and connected by logic gates. The process continues in the same way until all basic events are reached.

In Figure 3.8, the top event can occur if either the basic event E or the intermediate event F occurs. The EXCLUSIVE OR gate used to relate these events, indicates that either one can cause the top even to occur. The intermediate event F can be caused by either an intermediate event G, intermediate event H, or both of them. To relate them, an OR gate is used (i.e., the combination of the lower events could also cause the top event). Further analysis shows that the intermediate event G can only occur if the
conditioning event B was present when a basic event A occurred. This relationship is logically connected through the INHIBIT gate. Finally, the intermediate event H can only occur if both an intermediate event C and a basic event D occur at the same time, as shown by the AND gate used in the tree.

Figure 3.8: An Example Diagram of Fault Tree Analysis

Two evaluation techniques may be used to analyze a fault tree system: qualitative and quantitative analysis. In a qualitative analysis, the fault tree is constructed so that all
events or combinations of events that may lead to the system failure are included. Then, through Boolean algebra, the fault tree is analyzed to obtain its Minimal Cut Sets (MCSs). A MCS is the “smallest combination of component failures which, if they all occur, will cause the top event to occur” [Roberts et al. 1981]. It may consist of one cause or a combination of causes. However, if the set consists of a combination of causes, all of them must occur in order for the top event to occur.

In a quantitative analysis, the probability of the top event occurrence is calculated by using the probabilities of all the basic and conditioning causes leading to it. Furthermore, based on these probabilities, the MCSs can be ranked according to their importance. The higher the probability of occurrence of a set, the more important it is to the system (i.e., it has a higher probability of causing the top event), and the higher its ranking. However, in order to perform this analysis, we need to determine the probabilities for each of the basic and conditional causes in the tree. If they are to be relied upon, these numbers should come from the analysis of real data. Unfortunately, data regarding the causes of falls in the construction industry is still very limited. If certain sets of data are available, they often exclude the various variables and parameters that characterize a fall. Therefore, these sets of data are often ineffective for a fault tree quantitative analysis and can produce misleading results. For this reason, we have relied on the experience, heuristic judgment, educated guesses, and the rules-of-thumb of our experts and literature to perform a qualitative analysis for developing the fault trees.

One distinguishing advantage of fault tree analysis is its visual systematic procedure for identifying faults [Barlow and Lambert 1975]. As systems become more and
more complex, this analysis makes it easier for the analysts to determine all possible events that may lead to the system's failure.

For the creation of the SAFETY FIRST model, the fault tree model was chosen to represent the knowledge acquired from both literature and the experts. In this case, the top undesired event is going to be the fall of the worker from a predetermined surface (structural component) and the fault tree attempts to represent all the possible causes or combination of causes that could lead to the top event. The fault tree graphic system was chosen because it simulates the way the experts determine the cause of a fall accident, after it has already happened.

A previous study by Hadipriono [1992a, 1992b] shows how fault trees can be used to simulate the experts' deductive analysis to find the causes of a construction fall accident. Hadipriono uses a fault tree to try to determine the causes of a worker fall from a floor opening. To create the fault tree, the author had to make several assumptions, among which are the following: the focus of the fault tree was the worker and worker-related causes of fall; the component supporting the worker was assumed to be the floor, which in turn was supported by the joists; and finally, since the worker was working on the floor, it was assumed that no safety belts, lanyards, and/or safety lines were required. However, guardrails were required to prevent the worker from falling.

To be more specific, the top event of the tree is Worker Fall from a Floor Opening and is divided into Worker General and Worker Support causes, the latter containing the basic causes related to joist problems. The Worker General causes are divided into Worker Specific Causes and Safety Guard Condition. Both of these must
occur in order for the worker to fall since they are related by an inhibit gate. The causes under the *Safety Guard Condition* event are the conditional causes of fall, whereas the causes under the *Worker Specific* event are the basic causes of fall. The *Worker Specific* event is further grouped into causes internal to the worker (i.e., *Enabling*), causes external to the worker (i.e., *Triggering*), and causes related to the floor component (i.e., *Support*). These gates are further developed until basic causes are obtained.

This fault tree model was followed to develop the fault trees for all the structure components included in this study [Vargas 1993, Yoo 1994, Hadipriono et al. 1995]. However, there are several differences between the above fault tree and the ones developed for this project. There are differences in the assumptions, the components, and the levels of detail involved. All of these differences derive from the literature information available now and the cooperation of the experts involved with this project.
CHAPTER 4

FAULT TREE STRUCTURES FOR FALLS AND SLIPS

4.1 Introduction

As mentioned in Chapter 3, in order to develop a fault tree, the analysts must be thoroughly familiar with the system. Therefore, for this research project, the first step in the development process was to acquire knowledge and become familiar with potential events leading to falls (i.e., same level and higher elevation) and slips from building structures. The second step was to organize the information in order to develop the fault tree structures for the various accidents. The third step was to use the fault trees developed to identify the cause or combination of causes that may lead to previously mentioned accidents.

4.2 Causes of Construction Falls

As mentioned in Chapter 1, the causes of falls from the same level, slips, and falls from a higher elevation are studied here. For higher elevation falls, the following locations were identified to be the most significant since they account for most of the major injuries and fatalities: roofs, form scaffoldings, floor edges, floor openings, steel beams, ladders, wall openings, and tops of walls.
By using the fault tree systematic approach, the problems related to the working environment, the worker, and the equipment can be identified. For this study's purpose, the potential causes of these accidents are classified following the approach developed by Hadipriono [1992a], and used later by Vargas [1993] and Hadipriono et al. [1995a], namely basic and conditioning causes. Basic causes are primary failure problems which occur either by themselves or in combination with a conditioning cause leading to the occurrence of the accident. Conditioning causes are problems related to the safety devices or practices used in the system being analyzed. In most cases, these safety problems are not the primary cause of the accident; however, their existence enables its occurrence.

Under the same approach, the basic causes are grouped into the following categories: enabling, triggering, and support-related. Enabling causes include all the problems that are directly related to the worker (i.e., worker internal causes). Triggering causes include all the external problems that can affect the worker and cause the accident (e.g., environmental-related). Finally, support-related causes include all problems related to the structure where the work is being performed (e.g., roof). This is also a external cause, but of a more passive nature. The basic and conditioning causes of falls (i.e., same level and higher elevation) and slips will be discussed in the coming sections.

4.2.1 Causes of Falls from Higher Elevation

In general, most of the elevated structural components from which falls occur have many basic (i.e., enabling and triggering) and conditioning causes in common. However, the significance of each cause varies depending on the elevated component being analyzed.
Therefore, each cause will be discussed next: first, in general terms; and then, on an individual basis.

4.2.1.1 Basic Causes

As mentioned above, the problems which by themselves or in combination with safety problems (i.e., conditioning) can cause higher elevated falls are classified into triggering, support-related, and enabling categories.

4.2.1.1.1 Triggering Causes

Among the basic causes, triggering causes include any external event which could act upon a worker and cause or contribute to his or her fall. Triggering causes can be subdivided into those due to impact on the worker, those due to environmental conditions, and those due to distractions.

Under the impact-related causes, we include all cases when a worker is directly hit by a piece of equipment, piece of material, or another worker, and as a result loses his/her balance or is rendered unconscious, and then falls. In addition, if the fall occurred due to the worker’s attempt to avoid these hazards (e.g., moving towards the floor edge while trying to avoid being hit by a falling object), they are classified under this group.

Next, under the environmental-related causes are all natural events that may affect the working area, and can cause an environment propitious to falls. Among these weather-related factors are strong winds (gusts), rain, hail, snow, frost, fog, extreme cold, and extreme heat. These events could lead a worker to fall in different ways. A gust or strong
wind may directly cause a fall due to its impact on the worker. Certain conditions, like fog, rail, hail, and snow may reduce a worker's visibility and cause him/her to fail to recognize a fall hazard. Rain, hail, frozen snow, and frost could create slippery footing conditions on areas not protected by a roof (these causes could also be classified under support causes given that they occur on the working surface). Extremely cold or hot conditions can contribute to accidents because of a corresponding reduction in the concentration and care with which a worker performs his/her job. "At temperatures between 24 °C and 40 °C, each 1 °C rise in ambient temperature increases the physiological stress by 1 percent of the maximal work capacity. This is accompanied by increased sweating, increased heart rate, increased respiration rate, increased fatigue, and reduction in performance" [Fraser 1989]. Further, extremely hot conditions may lead to a worker’s dehydration, resulting in heat exhaustion which may cause the worker to collapse, or heat stroke which can be fatal. "Exposure to cold is accompanied by clumsiness and loss of dexterity. In this connection, cooling of the hands is of more significance than cooling of the body. The loss of dexterity is accompanied by a loss in touch sensitivity." [Fraser 1989]. Extremely cold conditions also require the worker to be bundled up, which can impede his or her motor skills and reaction times.

Finally, triggering causes due to distractions include any events in the work zone surroundings that could divert a worker’s attention for a given period of time and cause him/her to fall (e.g., if a traffic accident happens in a street near the work site, a worker may try to look and find out what happened and thus may not recognize a hazard to his/her life).
4.2.1.1.2 Support-Related Causes

They include, by definition, problems related to the structure or component supporting a worker while he/she performs a job. There are two main types of support related problems: first, problems that due to their seriousness may cause the collapse of the whole support structure or one of its components, leading to a worker fall; and second, problems related to the support component (e.g., floor) which could lead to a worker fall without causing the structure or its components to collapse.

In general, the causes related to the collapse of the support structure depend on the specific structural surface and location being analyzed; therefore, their causes will be specifically discussed in the coming sections. The other support-related problems are related to tripping or slipping hazards.

A slip is a temporary loss of balance resulting from a reduction or loss of friction between the worker and the supporting work area. It is "characterized by a sliding motion where the foot (shoe) loses traction with the walkway surface resulting in a loss of balance" [Szymusiak and Ryan 1982].

A trip is a loss of balance resulting from the worker’s foot or leg contacting an unexpected obstruction or “on occasion, too much friction between the foot or footwear and the walking surface” [Ellis 1994].

When walking, the body weight is alternatively carried by the right or the left foot as one foot is moved in front of the other. Four distinct contact phases are identified in a normal walking stride [Lin et al. 1995]:
1. The landing phase when only the rear part of the foot (heel) contacts the floor.

2. The stationary phase when the foot is flat on the floor.

3. The take-off phase when only the front part of the foot (toes) touches the floor.

4. The swing phase when the foot is being moved forward.

   Studies have shown that slips and trips occur when the smooth body weight transfer between feet is interrupted and the body is thrown off balance. Slips may occur during the landing phase (i.e., the heel of the foot touches the walking surface), when the foot slides forward, causing the body’s backward motion; or, during the take-off phase (i.e., the toes of the foot touch the walking surface), when the foot slides backward, causing a forward motion of the body. In both cases, the frictional forces between the floor surface and the worker’s shoes is not large enough to resist and overcome the horizontal forces generated during the walking stride.

   The coefficient of friction (COF) is used to evaluate the slip resistance of a surface given that it shows the magnitude of the frictional force acting between two surfaces. Two forms of COF are used toward that end: the static COF and the dynamic COF. In order to minimize potential slips, a currently accepted standard requires that the working surface should comply with the following minimum SCOF dry surface values obtained using a horizontal pull slip tester or a Brungraber device: 0.5 slip resistance in all areas (ASTM D2047), 0.6 resistance in walkways and level ramps, and 0.8 resistance in sloped ramps with a maximum slope of 1:12. These values do not consider the influence of the environment, the surface contaminants, the worker, and the shoe involved in a slip accident.
In addition to the roughness of the working surface, other factors that may contribute to the occurrence of slips include: the worker's shoes and contaminants that may reduce the contact area between the shoe and the working surface. The worker should use slip resistant shoes that will increase friction with the working surface and reduce the likelihood of him or her slipping. Further, the following contaminants on the working surface could lead to slips and falls: liquids, such as spilled oils or water; small debris or scraps from the work being performed; small materials, such as gravel, pipes, and bolts; and small tools.

Similarly, many hazards on the construction site can cause worker trips. Among these hazards are the following: loose boards, holes, bend plates, open drains, protruding nails in the working surface; projecting machine parts and pipe conduits above the working surface; hoses and cables and tools left on the working surface; boxes or materials inadequately stored on the working area; and unexpected level changes on the work surface (uneven walkways, bumps).

4.2.1.3 Enabling causes

The final type of basic causes, enabling causes are workers' internal causes affect the worker's ability to concentrate on and perform the job at hand. These enabling causes are grouped into health, attitude, and skill problems.

Health problems include sudden acute illnesses that attack the worker while on the job (e.g., heart attack) and cause him/her to collapse while performing a job on a fall prone working area (e.g., near a floor edge) and chronic illnesses which are illnesses that...
have been affecting the worker for most of his/her life, such as epilepsy. Chronic illnesses are significant if, at a given moment, they can cause a worker to lose control of his/her actions. In addition, a chronic illness could act on the worker over time, weakening him/her and diminishing his/her concentration and ability to recognize hazards. Worker's fatigue (physical) can also play a role in accidents. For example, the more tired the worker is, the lower his or her efficiency and the higher his or her likelihood to make mistakes that may lead to accidents and injuries [Vernon 1921, Sundstrom and Graehl 1986]. A final health-related problem is the use of prescription or over-the-counter drugs by the worker. These drugs could cause a worker to be drowsy or sleepy on the job. This is especially significant on fall prone areas where the consequences of a judgment error could be a serious injury, if not death.

Attitude problems are those caused by the worker's negative disposition toward his/her job. Within this group of enabling causes, we have the case when the worker goes to work drunk or drugged (after using illicit drugs), arriving to work with a 'hangover' or having a high blood alcohol content after a drink out night, or a drink at lunch time. "29 percent of employed Americans between the ages of 20 and 40 have used drugs at least once during 1989" [Hinze 1997]. Alcohol and drug use prevent the worker from being in full control of all of his or her senses; as a consequence, he or she is not able to recognize hazards until it is too late to prevent an accident. In addition, drug and alcohol use may impair the worker's judgment and lead to behavioral problems which may result in falls. Research in this area has found that drug abusers are 3.6 times more likely to injure themselves or another person on the job. A large number of injuries and deaths in the
industry can be attributed to these factors. For example, in Australia "25 percent of industrial accidents and up to 30 percent of industrial deaths are estimated to be alcohol or drug related" [Eilenberg and Coble 1996]. Another study indicates that workers who use marihuana or cocaine had 55 percent more industrial accidents and 85 percent more injuries than non-users [Zwerling et al. 1990].

The next group of attitude causes are problems related to the worker personality, which may cause a fall in several ways: if a worker chooses not to follow a supervisor's instructions regarding safety, if the worker tries to take shortcuts which may help him/her to finish his/her job quicker but may be very risky (which is the reason they are not used in the first place), or if the worker behaves in a reckless manner in an area where falls are very likely. Several research studies have found that the attitude of workers towards hazards will influence their practices (i.e., willingness to take higher risks). In addition, the lower the workers' fear of the hazard, the higher the risk-taking levels the worker is willing to take, and the higher the likelihood of accidents [Spaltro 1967, Rockwell 1967, Molinder and Mosinger 1967, and Harper and Kalton 1968].

Another attitude-related enabling cause includes distractions due to stress. Family, financial, and other personal problems can weaken a worker's concentration on a job and ultimately may enable a fall to occur. According to Hinze [1996], depending on the level of the worker focus on these distractions, the probability of injury will increase and the worker's productivity will decrease. Further, Hinze also argues that the worker awareness of physical hazards and unsafe conditions and his or her focus on them may act as a distracting force which will produce the same injury and productivity results.
Finally, among the enabling causes related to skill, we have the following: lack of training, lack of experience, and low aptitude for learning. Lack of training can cause a fall because a worker may fail to recognize a hazard or to react properly when an incident happens. It is also accepted that the broader the experience of a worker, the less likely he/she is to fall. This is because he/she does not take any unnecessary risks and he has the experience to identify hazards and to know what measures are necessary to avoid fall accidents. In general, the more experienced the worker is on the job at hand, the better his or her chances are of avoiding accidents. However, the experience the worker has should be directly related to the task at hand, otherwise it would not be significant. For example, if a worker has 25 years of experience in the construction industry mostly performing jobs where fall hazards never occurred, then this experience would not be of value to him or her at the time of a fall. Finally, the lack of aptitude cause indicates a problem in which a worker's capacity both to learn from experience and/or training is questionable; therefore, the worker may still take unnecessary risks or be unable to react properly to risky situations.

Usually, enabling causes can lead to falls only if they occur in combination with other conditioning causes and/or other basic causes. For example, a fall from a floor edge may be due to the worker tripping on a tool left on the floor of the working area (support-related cause) which he or she failed to notice due to his or her being distracted by problems at home (enabling cause) which prevented him or her from being as alert as usual; and finally, to complicate the matter further, the floor edge was not protected by a fall protection device, such as a guardrail system (conditioning cause). There are some
exceptional cases in which the fall may be directly due to an enabling problem such as when the worker collapses due to a health or intoxication problem.

4.2.1.2 Conditioning Causes

These are problems or conditions in the system that, if combined with primary causes, enable the occurrence of a fall accident. They are significant since their avoidance can in most cases prevent accidents from happening. Furthermore, since these causes are mostly related to problems with the safety measures in a construction site, construction companies have a great deal of control over them. Here, the conditioning causes are grouped into problems with general safety measures on the site and problems with the fall protection/prevention safety measures on the site.

4.2.1.2.1 General Safety Causes

Problems with general safety measures include safety problems that may contribute to falls or slips, but are not related to fall protective equipment, including the following: (1) the lack of or inadequate overhead protection when there is work going on above the working surface (if there is no overhead protection, falling materials may hit a worker and cause his or her fall), (2) poor housekeeping around the work zone (e.g., failure to keep the working surface clean from slippery substances and small materials and failure to cover small holes in a floor, problems which can cause a worker to slip or trip and lead to a fall accident), (3) inadequate personal protective equipment (e.g., lack of hard hats), (4) inadequate or lack of training, and (5) lack of other safety measures.
4.2.1.2.1.1 Protection from Falling Objects.

Falling objects are a major cause of falls and other accidents on the site. In order to prevent falling objects from hitting workers or pedestrians at a lower working/walking surface, the contractor should take the following measures:

- All guardrails of overhead working surfaces should have a toeboard erected along the edge.
- If tools, equipment, or materials are piled higher than the top of the guardrail’s toeboard, screens or wood panels should be erected at a height large enough to prevent objects from falling to the lower working surfaces.
- Canopies can be used to protect lower working or walking areas from falling objects. They should be strong enough to prevent collapse and penetration from falling objects.
- Barricades can be used to prevent employees from entering areas from which objects could fall.
- A preferred practice would be to maintain all potential falling objects (e.g., materials, equipment, tools, and debris) away or clear from the edges or openings.

Though signs can be a useful tool to warn workers about hazards, signs alone are not acceptable substitutes for barricades to prevent worker exposure to falls or falling objects hazards.

As for the toeboards, in order to be effective, they should comply with the following characteristics:

- They should be capable to withstand, without failure, a force of at least 50 pounds (222 N) applied at any point of the board and in a downward or outward direction.
• They should have a minimum height equal to 3.5 inches (9 cm).

• They should not have a clearance of more than 0.25 inch with the working surface.

• They should be solid or have no openings larger than 1 inch (2.5 cm) in its greatest dimension.

During the performance of overhand bricklaying and related work, no materials or equipment (except masonry and mortar) should be stored within 4 feet (1.2 m) of the working edge, and all excess mortar and other debris should be kept clear from the work area and removed at regular intervals.

During roofing work, materials and equipment should not be stored within 6 feet (1.8 m) of the edge (unless a guardrail and barriers are erected at the edge), and materials piled near the edge should be stable and self-supporting (i.e., they will not collapse unexpectedly).

4.2.1.2.1.2 Site Housekeeping.

Most slip and trip accidents are caused by problems related to objects or substances on the working surface. Many of these problems could be avoided with adequate housekeeping practices, such as the following:

• The working surface should be maintained free from slippery debris or other substances. For example, spilled oils or water should be immediately cleaned up, power tool cords should be kept out of the way, scraps and litter should be removed periodically from the working surface. Adsorptive materials may be used to clean up spills.
- High traffic areas should be maintained uncluttered. Store materials in specific predefined areas far from fall prone components.

- Temporary or permanent barricades should be used to prevent workers from entering the hazardous area (e.g., spill).

- The visibility of new or temporary hazards should be increased by using warning signs (e.g., Caution - wet floor, Caution - watch your step, etc.) and barriers.

- The work area should be well lit. Poor lighting can prevent workers from seeing and reacting to potential hazards on the site.

- The working zone should be regularly inspected by all parties in the site (i.e., management, workers, subcontractors, etc.).

- Broken or faulty equipment should be removed from the field and labeled, avoiding its use by an unsuspecting worker who would use the tool unaware of its defects.

- During steel erection, at least two bolts should be used to secure the beam at each end. This will prevent the beam from rolling over (i.e., turning on itself) when being stepped on. Further, this will also reduce the likelihood the steel structure will fail due to external factors (e.g., equipment impact).

- During roofing, steel erection, and scaffolding work, all slipping hazards should be removed before starting work.

4.2.1.2.1.3 Personal Protective Equipment.

As for personal protective equipment and falls, shoes, hard hats, and fall arrest and positioning devices are the most important devices for protection from falls.
The worker's safety shoes should be slip resistant. "The best shoe soles possess some elasticity to conform to a walking surface, and have a surface roughness that interlocks with the walking surface" [Kaufmann 1994]. "Proper footwear can reduce employee falls by more than 50 percent" [Kohr 1994].

Hard hats should always be worn by people on the site to protect them from overhead falling or flying hazards. "Each year, the Rehabilitation Institute of Chicago treats several construction workers who suffer brain injuries in falls or other accidents where their heads are struck" [McManamy 1997]. In addition, hard hats with chin straps can prevent the hats from falling off the worker's head and help reduce the severity of head injuries during falls.

Belts for positioning and harnesses for fall protection should be used in areas from which falls may occur and which are not protected by other devices, such as guardrails, safety nets or covers.

Other personal protective equipment, such as safety glasses, should be used as the site conditions warrant it. For example, the worker should bundle up for cold weather conditions, including wearing gloves to prevent the body heat from escaping. For hot working environments, water should be available in the working area to prevent dehydration of workers.

4.2.1.2.1.4 Worker Training.

The employer should train workers to follow the company's safety policies and OSHA standards. The company's safety program should outline the behavior expected
from the worker and the practices and devices to achieve a safe site. Further, the new OSHA standards for fall protection require the employer to provide training (CFR 1926.503) for each employee who might be exposed to fall hazards. The training should enable each employee to recognize the hazards of falling and train each employee in the procedures to be followed in order to minimize these hazards. OSHA recommends that employees should be trained in the following areas:

1. The nature of fall hazards in the work area.
2. The correct procedures for erecting, maintaining, disassembling, and inspecting the fall protection systems to be used.
3. The use and operation of guardrail systems, personal fall arrest systems, safety net systems, warning line systems, safety monitoring systems, controlled access zones, and other protection to be used.
4. The role of each employee in a safety monitoring system approach.
5. The limitations on the use of mechanical equipment during the performance of work on low-sloped roofs.
6. The correct procedures for the handling and storage of equipment and materials and the erection of overhead protection.
7. The role of employees in fall protection plans.

These items outline the minimal knowledge a worker exposed to fall protection hazards should know and therefore should be exposed to during a fall protection training course. However, they are by no means comprehensive. Other areas of knowledge in which the worker should be trained include the following:
To recognize his or her physical limitations so as to avoid unnecessary exposure to slips. For example, trying to lift or move excessively heavy objects.

- To develop a safety conscious attitude (e.g., watch where they walk).
- To pay attention to warning signs.
- To recognize hazards and react appropriately to them.
- To follow good housekeeping practices.
- To use proper personal protective equipment (PPE), including footwear.

Further, OSHA standards do not limit the employer's responsibility in providing knowledge, they require the employer to verify that all of the knowledge above was learned by the worker. Towards that end, OSHA requires the employer to prepare and keep on file a written certification record which should contain the following: the name or other identity of the employee trained, the date(s) of the training, and the signature of the person who conducted the training or the signature of the employer. If the employer relies on training conducted by another employer or completed prior to the effective date of this section, the certification record should indicate the date the employer determined the prior training was adequate rather than the date of actual training. If the employer has reason to believe that a worker previously trained has not acquired the knowledge and skills mentioned above, the worker should be retrained.

In addition, research indicates that workers new to the job site are especially vulnerable to accidents and "it is possible to obtain a dramatic reduction in accidents by simply reducing the risk of injuries to the most vulnerable sector of the construction work force--new workers. Note that 'new workers' in this context means any workers who are
new to a project, no matter how old or experienced they might be ... The single most important thing a job-site manager can do for anyone coming on the project is to ensure that the person is well-oriented ... The construction environment is filled with potential hazards; no two projects are alike; and each project is constantly changing. That is what makes construction challenging and exciting, but that is also why it is potentially so dangerous. Keeping the project safe depends then on keeping everyone informed and aware” [Levitt and Samelson 1993]. Therefore, employees new to the job site should receive orientation. The following are some aspects to consider when orienting new workers [Levitt and Samelson 1993]:

- The worker’s past work and safety experience.
- The new job and job rules need to be explained to the worker.
- The site and potential hazards are shown to the worker.
- New crew members are started slowly and their behavior monitored early on.

4.2.1.2.1.5 Other Safety Practices.

The contractor should have a safety program to deal with other potential problems that may arise during site work. For example, it should have a medical plan to detect on advance any potential health hazard that could affect the worker’s performance in the site. The worker ability to perform well on a job depends partly on his or her physical ability. A medical exam could help detect certain health problems which might affect the worker’s performance on the site (e.g., hearing or vision problems, the worker’s fear of heights, acute illnesses such as heart problems, tuberculosis, etc.). The detection of these problems
should influence the type of work the worker is assigned to. For example, a worker who suffers from epilepsy should not be assigned to work at higher elevations where he or she may fall if a seizure occurs.

Further, “drug and alcohol abuse is currently a subject of great concern to construction managers at all levels. A worker whose judgment or alertness is impaired by alcohol or drugs is clearly a hazard not only to himself or herself, but also to the lives and property of others engaged in construction” [Levitt and Samelson 1993]. Therefore, the contractor should have some policy for dealing with alcohol and drug abuse as potential hazards. This policy may include the following:

- Educating workers about the hazards of alcohol and drug use.
- Taking blood or urine samples from workers for drugs analysis. Workers who test positive for drug tests should be removed from the site and referred to services for rehabilitation and treatment.
- Removing from its job site anybody who there is reason to believe is involved in furnishing, selling, using, or being under the influence of alcohol or drugs.

4.2.1.2.2 Fall Protection/Prevention Causes

These conditioning causes are mostly related to the fall protection/prevention measures used at elevated components from which falls could occur. These causes are analyzed in more detail since they directly influence the occurrence of construction falls from higher elevations. There are two main causes related to these fall protection/prevention measures: the first occurs when there are no fall protection or
prevention devices installed on the elevated component; the second, when such a device or a combination of devices is provided, but is inadequate for the job.

Causes related to missing fall protection devices are easy to identify since they are very obvious. The inadequacy of a fall protective device is harder to determine, because it depends on the device being used and the location it is being used at. Among the devices that may be used for elevated components fall protection/prevention are the following: a standard guardrail, a safety net system, a fall arrest system, a catch platform, an opening cover, a warning line system, and a controlled access zone (CAZ).

The selection and use of fall safety devices depends on the elevated structural component being studied. The devices used for one component may not be effective or practical for a different one. For example, a guardrail system is clearly inadequate to prevent falls during steel frame erection procedures. The specific devices that can be used for each elevated structural component will be discussed in the ensuing sections. The problems related to the inadequacy of each of the devices are discussed next.

4.2.1.2.2.1 Inadequate Guardrail System Causes

A guardrail system is a barrier erected at unprotected edges and holes where there is a drop of more than 6 feet (1.8 m). Its main objective is to prevent workers from falling to lower levels. It usually consists of four main components: a top rail, a middle rail, a toe board, and posts. Other components that may be used are: intermediate vertical members (IVM), solid panels, or screens or mesh. These may be used in addition to the four main
components or they may replace the middle rail and toe board. The following are the main hazards associated with the use of guardrails:

1. The guardrail system collapses or fails under the falling worker impact. This failure may be due to the failure of one of the components (e.g., top rail) listed above, or the failure of the connections between the rails and the posts or the posts and the working surface.

2. The guardrail system, as erected, allows the worker to fall through an unprotected area above the top rail or between the guardrail components (e.g., between the top rail and middle rail or between the middle rail and the toe board or floor).

3. The guardrail system does not protect a certain fall area or is temporarily removed for certain operations.

In general most of these hazards can result in falls if the guardrail uses inadequate materials, the guardrail is inadequately erected, or if the guardrail is inadequately used.

There are two cases when the guardrail materials may be inadequate: first, when the original material is not up to strength standards; and second, when the materials are not up to standards due to excessive wear. In general, a guardrail when completely built should be able to withstand a load of at least 200 pounds (890 N). In addition, the intermediate rail or any other intermediate component should be able to stand without breaking under a minimum load of 150 pounds (666 N). Finally, the toeboard should be able to withstand without failure, a force of at least 50 pounds (222 N). All of these loads should be applied in an outward or downward direction and at any point of component being tested. Usually the strength of the guardrail components can be evaluated according to the
material they are made of and their cross sectional size. For example, in the case of a pipe railing, the post and the rails should be at least 1.5 inches (38.1 mm) in diameter to comply with the required strength standard. The excessive wear conditioning cause will include cases when the material components used to build the guardrail are up to size and strength requirements, but excessive use has reduced their strength. Examples of excessive wear problems are corrosion, abrasion, and any other damage done while moving, assembling, or disassembling the guardrail.

According to the new fall protection standards of OSHA [CFR 1926.500 1994], the erection of a guardrail should comply with several requirements; for example, the top rail elevation should be at an elevation of 42 plus or minus 3 inches (1100 plus or minus 80 mm), the mid-rail should be located half-way between the top rail and the floor (i.e., about 21 inches or 550 mm), and the toe board should extend at least 4 inches (102 mm) above the floor. In addition, the posts supporting the rail should be spaced 8 feet (2.4 m) apart or less (if required). This spacing is specially important, if the contractor is using the material cross-sections suggested by the OSHA standards. Violation of these requirements during construction could be considered a conditioning cause of a fall. For example, if the elevation of the top and mid rails is too high, then the space between the mid rail and the toeboard will be too large and the worker may fall through it. The same case occurs if the spacing between the top and mid rails is too large. If the top rail is located at an elevation too low, the worker may fall over it. Further, if the post spacing is more than 8 feet (2.4 m), the guardrail may deflect too much in the case of impact and again fail to prevent a fall.
In addition to the problems with the elevations and rails spacing, there is the situation in which some components are missing from the guardrail (e.g., no mid-rail) and therefore some area of the guardrail is unprotected and a worker may fall through it. A common occurrence on construction sites is that contractors deem toeboards as non-essential components and as a consequence do not install them; unfortunately, toeboards could be the only protection for a worker who slips towards the edge may have before falling.

In addition, if the connection between the rails and the posts or the posts and the working surface (e.g., floor) is inadequate, the guardrail may fail at that connecting point. These connections should also be strong enough to withstand a 200 pound load. Further, the rail-post connection should transfer the load from the rails to the posts; therefore, the rails and intermediate components should be located at the inner part of the working surface and the posts at the outer part or drop area. If the rails are at the outer part (falling area), the bulk of the impact will have to be supported by the connection which is likely to fail. As for the connection between the posts and the floor, most of them will be provided by the guardrail’s manufacturer. However, if a wood rail is being used, most experts recommend the use of a diagonal brace between the post and the working surface. This brace could be a 2x4 piece of lumber, or a piece of plywood of triangular shape.

Other installation-related potential causes include the following problems:

1. If the ends of the top and mid rails cause additional protection hazards, they should not overhang their terminal posts. For example, if the rails overhang towards the working surface, they could create obstacles which might cause a worker to trip.
2. If a guardrail system is used around a hoist area; a chain, a gate, or a removable guardrail section should be placed across the point of access between the hoist and working area. Another option is to offset the guardrail ends so that a distracted worker cannot accidentally walk into the hoist area and fall.

3. If a hole is used as an access point (i.e., ladder way) to the working surface, a chain, a gate, or a removable guardrail section should be placed across the access point between the hole and the working surface. A guardrail offset segment could also be used here so that a worker cannot accidentally walk into the hole.

Finally, the inadequate use causes include problems related to the inadequate use of the guardrail system. A common problem with the use of wire rope rails is their temporary removal during certain construction operations (e.g., during a hoist operation of a large piece of material where the top and middle rails are an obstacle). If guardrail is removed, other fall protection methods should be used to secure workers from falling (e.g., fall arrest system). A better solution to prevent this problem would be to plan ahead for such contingencies (e.g., adding a hoisting area to bring materials onto the working surface so that the guardrail system does not have to be removed). If a guardrail system is used around a hoist area, it does not mean that the workers inside the area are protected. Another safety device (i.e., safety net or fall arrest) should be used to protect workers inside the hoist area. If a guardrail is used for hole protection, it should be erected around all the edges of the hole. A maximum of two sections of guardrail should be removable if the hole is used for the passage of materials; however, these sections should be closed
when the hole is not in use. Other means of protection should be provided to the workers handling materials around the unprotected hole.

4.2.1.2.2 Inadequate Safety Net System Causes

A safety net system is a net structure erected underneath an elevated working surface’s component (e.g., floor or roof edge, floor hole, etc.) exposed to falls. Its objective is to catch workers in the case of a fall.

The safety net system has the advantage of not requiring the active participation of a worker in order to be effective. However, it has two disadvantages in that it is cumbersome to erect and it requires constant maintenance. The following hazards are associated with the use of safety nets:

1. The safety net or a safety net component fails under the worker impact
2. The safety net fails to catch the fallen worker.
3. The fallen worker is injured due to fall impact.
4. The fallen worker is injured after a member of his or her body goes through a net opening (e.g., the worker breaks his or her neck after his or her head goes through the opening).
5. The fallen worker is injured after net hits lower work surface due to impact deflection.
6. The fallen worker is injured after hitting a piece of scrap material or debris on the net.

As with guardrails, these hazards can result in falls or excessive worker injuries if the safety net uses inadequate materials, the net is inadequately erected, or the net is inadequately used. If the materials used to build the net are not up to impact resistance
standards, the net system may collapse and fail to fulfill its function. The new fall protection standards require that the net be able to stand an impact load similar to that generated through a drop test using a 400 pound (1780 N) bag of sand with a 30 inch (765 mm) diameter dropped onto the net from the highest working surface from which a fall may occur but no less than 42 inches (106.68 mm) above that surface (According to OSHA, this last measure is to take into consideration the center of gravity of the 95th percentile man). In addition, OSHA requires that the edge ropes, the lacing material, shackles, safety hooks, and other components of the safety net system be able to provide a minimum breaking strength of 5,000 pounds (22.2 kN). These impact load resistance requirements would not be met if either the materials originally used were not up to standards (i.e., were undersized) or if the components were originally up to standards but have been worn out by excessive use.

A safety net system may be deemed inadequately installed if the net is used at elevations below 25 feet or is located more than 30 feet (9.1 m) below the working surface it should protect. The net should be located at an elevation high enough so that there is enough clearance under it to assure that the worker will not hit solid ground after the deflection due to impact. Further, the area immediately below the net should be free from obstructions the worker may hit after the net deflects due to the fall impact. In addition, a 30 foot (9.1 m) or higher fall could injure the fallen worker due to the impact with the net. In addition, if a worker were to fall a significantly longer distance the net system might not be able to withstand the impact load of the fall and the worker could fall all the way to the ground or to the nearest surface.
Further, depending on the falling distance allowed by the net, it should extend a minimum distance beyond the working surface’s edge in order to be effective. Previously, this distance was fixed at 8 feet (2.4 m); however, drop test studies have indicated that depending on factors such as the wind and the worker outward momentum at the time of the fall, and the falling distance to the net; the worker may go as far as 20 feet (6.1 m) from the floor edge. This is the reason why the new fall protection standards by OSHA specify three minimum outward distances (Table 4.1). The use of projecting distances below those specified could facilitate a worker fall. Any violation of these requirements may cause the net system to be deemed inadequate and fail to prevent the worker from falling all the way to the ground.

<table>
<thead>
<tr>
<th>Vertical Distance from Working Level to Horizontal Plane of Net</th>
<th>Minimum Required Horizontal Distance from Working Surface Edge to the Net’s Outer Edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 5 ft (1.5 m)</td>
<td>8 ft (2.4 m)</td>
</tr>
<tr>
<td>From 5 ft (1.5 m) to 10 ft (3 m)</td>
<td>10 ft (3 m)</td>
</tr>
<tr>
<td>More than 10 ft (3 m)</td>
<td>13 ft (3.9 m)</td>
</tr>
</tbody>
</table>

Table 4.1: Minimum net projections depending on the vertical distance between the working surface and the net
Other potential installation problems that could affect the safety net’s performance include the following:

1. Poor connections between the safety net and its supports (i.e. border webbing) or poor connection between safety net panels. The net should be laced at intervals of 6 inches (150 mm) or less.

2. Use of inadequate safety net. OSHA limits the maximum allowable mesh opening to 36 square inches (230 square centimeters). In addition, the mesh opening shall not be longer than 6 in (15 cm) on any side and the opening measured center to center of mesh ropes or webbing, shall be no longer than 6 in (15 cm). Further, in order to prevent enlargement of the mesh opening, all mesh crossings on the net shall be secured (i.e., tied). This will also eliminate the frictional wear of the net’s strands.

Finally, only one potential cause is due to inadequate use, the case when materials, scrap pieces, and tools which have fallen into the net shall be removed as soon as possible, at least before the next work shift. This is in order to prevent a falling worker from hitting them.

4.2.1.2.2.3 Inadequate Fall Arrest System Causes

A Fall Arrest System is a device worn by the worker that uses a body harness or a safety belt to arrest or reduce the consequences of a fall. It includes all the components required to properly use the harness to control a fall; such as an anchorage point, a lifeline, a lanyard, shock absorbers, and connectors.
These causes are classified into material, installation, and use problems. If any of the system's components strength is inadequate, it will cause the whole system to fail and allow the worker to fall all the way to the ground. Strength problems may occur if the component original strength is deficient or it has been reduced over time (i.e., worn out). The following are the strength requirements of all the system components:

1. The anchorage point should be able to support a minimum load of 5000 pounds (22.2 kN) per employee attached; or be designed and installed under the supervision of a qualified person, and used as a part of a fall arrest system with a safety factor equal to 2.

2. Connectors and snap hooks should be able to withstand a minimum tensile strength of 5000 pounds and should be proof-tested to a minimum tensile load of 3600 pounds without cracking, breaking, or deforming permanently.

3. A horizontal lifeline should be designed, installed, and used under the supervision of a qualified expert and designed with a minimum safety factor equal or larger than 2.

4. Vertical lifelines and lanyards should be able to withstand a minimum breaking strength load of 5000 pounds (22.2 kN). Only one employee should be attached to each lifeline.

5. Self-retracting lines and lanyards which automatically limit the free fall distance to less than or equal to 2 feet (0.61 m) should be able to withstand a minimum tensile load of 3000 pounds (13.3 kN) applied to the device with the lifeline or lanyard in the fully extended position. If a self-retracting line or lanyard does not limit the free fall distance to 2 feet or less, or if a ripstitch lanyard or tearing and deforming lanyard is being used;
they should be able to withstand a minimum tensile load of 5000 pounds (22.2 kN) applied to the device with the lifeline or lanyard in the fully extended position.

6. Any other component of the fall arrest system whose strength is not otherwise specified should be able to withstand a minimum fall impact load of 5000 pounds (22.2 kN). However, if the system is being used by an employee having a combined person and tool weight of less than 310 pounds (140 kg) and it passes the tests outlined below, the system will be considered to be in compliance with the requirements above. Otherwise, the test loads should be modified according to the actual maximum load expected.

Other potential problems related to materials selection occur if the following requirement are not met:

1. Connectors and snaphooks should be drop forged, pressed of formed steel, or made of equivalent materials, should have a corrosion resistant finish, and their surfaces and edges should be smooth to prevent damage to interfacing parts.

2. All ropes and straps (webbing) used in lanyards, lifelines, and other strength components of the belt or harness should be made from synthetic fibers. Natural fiber rope's strength deterioration with age is at times not detectable; however, studies have shown that weathering and sun exposure can greatly affect its performance.

Finally, all components of the system that show signs of wear, damage, or other deterioration should be removed from service given that their load bearing capacity may be compromised. The following are examples of wear or damage: cuts, tears, abrasions, mold, undue stretching, alterations or additions which may affect efficiency, damage due
to contact with fire, acids, or other corrosives, distorted hooks, faulty hook springs, tongues unfitted to the shoulder of buckles, loose or damaged mountings, non-functioning parts, wear on ropes, etc.

As for the installation related problems of the fall arrest system, the following cases should be considered:

1. The anchorage point allows the lanyard to slip out of it.

2. The anchorage point requires the worker to be exposed to a fall hazard while reaching to connect to it.

3. The anchorage point location allows the occurrence of a swing fall where the fallen worker may hit an obstruction down below. The fall path should be checked before the worker is allowed to use the system.

4. The use of knots to tie-off a lanyard or line may significantly reduce their strength.

5. The fall arrest system forces the worker to disconnect in order to reach certain exposed point on the working surface.

6. The fall arrest system allows an excessive arrest force on the worker. The system still causes injuries to the worker. A fall arrest system using a body harness should reduce the fall arrest force on an employee to 1800 pounds (8 kN). Studies have shown that employees are able to withstand a force 10 times their weight. The 1800 pound force limit assumes the average employee weight to be 180 pounds.

7. The fall arrest system allows a excessive fall distance. The fall arrest system should bring the worker to a complete stop, limit the free fall distance to less than or equal to 6 feet (1.8 m) or the free fall distance allowed by the system manufacturer, and limit
the deceleration distance allowed to less than 3.5 feet. Otherwise the fall impact may
induce serious injuries on the worker.

8. The fall arrest allows the worker to hit obstacles or a working surface down below.
The distance between the working surface and the ground or nearest surface should be
smaller than the free fall distance allowed by the system (i.e., worker should not hit a
lower surface during the fall). The following factors should be considered when
determining the falling distance:

- If the connecting point of the lanyard to the lifeline or anchor is at a point lower
  than the connecting point of the fall arrest and the harness, the free fall distance will
  be increased.

- A deceleration device activation will result in an additional stopping distance (i.e.,
  after engaged).

- While arresting a fall, the lanyard and lifelines will experience a length of stretching
  (i.e., elongation).

Finally, the fall arrest system will be inadequately used if any of the following
events occur:

1. A safety belt is used as a part of a fall arrest system. As of January 1st, 1998, safety
   belts are not an acceptable component of a fall arrest system. Their use is acceptable
   for positioning or ladder safety devices. In those cases, they are not used to arrest falls.
   The reasons a safety belt use is no longer allowed in fall arrest systems include the
   following:
1. The belt is worn on the waist and persons who fall wearing belts cannot tolerate suspension long enough to allow for rescue.

- The fall impact and pressure exerted during a fall makes them inappropriate for use in a personal fall arrest system. The impact of the belt on the worker's waist may cause back or more serious (e.g., breaking a vertebra causing paralysis of the lower half of the body) injuries. The practice of wearing the belt with its attachment point on the front of the body increases the danger of serious injuries because it causes the worker to fall backwards.

- The worker may fall out of the belt during a fall, especially if the belt is not appropriately tightened.

2. The use of non-locking snaphooks as a part of the fall arrest system. As of January 1, 1998, only locking snaphooks should be used in a fall arrest system. The use of locking snaphooks is preferred over the non-locking ones. They eliminate roll out problems (i.e., the keeper of the hook is accidentally opened during a construction operation, releasing the connecting component). The following are conditions under which disengagement of non-locking snaphooks may occur:

- When the snaphook sizes are not compatible with those of the connected members.
- When the snaphook is directly connected to webbing, rope, or wire rope.
- When the snaphooks are connected to each other.
- When two snaphooks are connected to the same dee-ring.
- When the snaphooks are connected to a horizontal lifeline.
3. Only one employee should be attached to each lifeline. If one employee falls, the movement of the lifeline during the arrest of the fall may pull other employees’ lanyards, causing their fall. For employees working on a hoist way (elevator shaft) and a top a false cart equipped with a guardrail, two employees may be attached to the same lifeline, provided that the lifeline strength is 10000 pounds (44.4 kN) (i.e., 5000 pounds for each employee). This exception is allowed to avoid the potential for two separate lifelines getting entangled. In this case, the fall of one worker may cause the second worker’s fall (i.e., the worker is dragged by the lifeline).

4. Using a knot in a rope lanyard or lifeline at any location can reduce the lanyard or lifeline strength by 50 percent or more. Therefore, if a knot is used, the following measures could be taken to control this problem:
   - A stronger lanyard or lifeline should be used to compensate for the weakening effect of the knot.
   - The lanyard or line length may be reduced to reduce the free fall distance and the load force.
   - The lanyard or lifeline could be replaced by one with connectors which eliminate the need of using a knot.

5. A tie-off using a “one-and-one” sliding hitch knot (prusik) should never be used for lifeline-lanyard connections. It is unreliable in stopping falls. The “two-and-two” or “three-and-three” sliding hitch knot may be used in emergency situations; however, they may reduce the line strength by up to 70%.
6. A lanyard or lifeline tied-off around an H or I beam or similar support can lose their strength by as much as 70 percent due to the cutting action of the beam edges. Therefore, if used, a webbing lanyard or a wire core lifeline could be used around the beam, the lanyard and lifeline should be protected from the sharp edges of the beam, or the free fall distance allowed by the system should be greatly minimized.

7. If the line passes around or over rough or sharp surfaces, its strength can be drastically reduced. An alternative tie-off rigging should be used to avoid the rough surfaces, an abrasion resistance strap or padding should be used around or over the problem surface, or a wire rope tie-off should be used.

8. Depending on their geometry and angle of sag, horizontal lifelines may be subject to greater loads than the impact load imposed by an attached component. If the angle of sag is less than 30 degrees, the impact force imparted to the lifeline by an attached lanyard is greatly amplified:
   - For a sag angle of 15 degrees, the force amplification is about 2:1.
   - For a sag angle of 5 degrees, the force amplification is about 6:1.

Therefore, the lifeline and its anchorage strength should be increased that number of times over that of the lanyard.

9. Finally, if a horizontal lifeline has multiple tie-offs, the strength of the line and anchors should be increased for each additional employee to be tied-off. Further, the designer should consider the impact of a falling worker on other workers tied to the lifeline (i.e., movement may cause other workers to fall). Therefore, the line should be
designed by a qualified person. OSHA recommends that the lifeline be tested prior to use.

4.2.1.2.2.4 Inadequate Hole Cover Causes

A standard hole cover is used to guard floor or roof holes. A major problem with covers is the use of inadequate materials, causing it to fail under the worker weight. The cover should be able to withstand at least twice the maximum weight imposed on it. Therefore, if the cover is located on a place where vehicles or equipment will be expected to cross over it, the cover material should be able to withstand at least twice maximum axle load of the largest piece of equipment expected to operate on the area. If no vehicle or equipment operation is expected, the cover should be able to withstand at least twice the weight of the heaviest employee carrying his or her tools. Further, the tear and wear of the cover under the elements may reduce its strength; therefore, it should be inspected for signs of fatigue or wear which may reduce its load bearing capacity and replaced if any such signs is detected. A common problem on construction sites is the placing of materials or tools on top of the cover for prolonged periods of time, affecting the cover’s load bearing capacity.

Other potential problems occur if the cover is accidentally displaced and tips over inside the hole under the worker weight. Also, if the cover is not large enough to protect the entire hole, the worker can fall through an unprotected area or step on an unsupported area causing the cover to fail. To prevent these problems, the cover should be large enough to protect the entire hole and be secured in place.
Finally, a hole may be left unprotected after its cover is intentionally removed by a worker performing housekeeping chores (i.e., worker confused it with a plain piece of wood or litter). To prevent accidental removal, the cover should be color coded or labeled with the words “cover” or “hole” to identify it.

4.2.1.2.2.5 Inadequate Catch Platform Causes

The catch platform is a structure erected next to or underneath the structural component being protected. Usually, this structure is a scaffold and is mostly used to protect sloped roofs so that if the worker falls he/she will roll into it instead of falling all the way to the ground. They are also used to protect floor edges and flat roofs. The catch platform structure should be erected next to and at the same level of the component being protected so that the scaffold’s guardrail fulfills the main fall protection function. It should also be noted that this device is not commonly used for surfaces which are on very high elevations, where its erection is not practical. A catch platform is inadequate to prevent falls if it is inadequately erected (e.g., not installing all the bolts for the braces supporting the structure) or the materials used to build it are faulty or of inadequate strength. Both of these cases may cause the structure to collapse under the load generated by the worker’s weight. In addition, any of the aforementioned problems with the structure’s guardrails may cause it to fail to fulfill its purpose.
4.2.1.2.2.6 Inadequate Warning Line System Causes

A warning line is a barrier erected on a low-pitched roof to warn workers when they are approaching the unprotected roof side or edge. It designates an area within which roofing work may take place without the use of a guardrail, safety net, or a fall arrest system. Its use is allowed when work operations do not require workers to be near the roof edge. This system should be used only when the work being performed is in the interior of the floor or roof (i.e., not near the edge) and after the worker has been thoroughly trained to recognize that the lines indicate a dangerous proximity to the edge. In general, problems with this device can be grouped into those due to the use of inadequate materials, improper installation, and improper use.

Inadequate material problems occur if the warning line components fail to meet OSHA's strength and tension requirements. OSHA requires that the warning line system be able to withstand a horizontal force of at least 16 pounds (71.04 N) without tipping; furthermore, the line should be able to withstand a minimum tensile strength of 500 pounds (2.2 kN).

Inadequate installation problems include cases when a warning line is erected too close to the edge and does not give the worker enough time to react and avoid a fall accident. If no mechanical equipment is being used, the line should be erected no less than 6 feet (1.83 m) from the edge. If mechanical equipment (i.e., motor or human propelled wheeled equipment, except wheelbarrows and mop carts) is used, the distance should be increased to 10 feet (3.05 m) in the edge perpendicular to the equipment direction. In addition, the connections between the lines and the stanchions (posts) should be such that
impact in one section (between two stanchions) does not cause other sections to be affected. Otherwise, the impacted section may deflect too much and fail to stop the worker. Further, if the warning line elevation is too high, it may fail to warn the worker he or she is approaching the edge; or if its elevation is too low, it may cause a worker to trip or lose his/her balance and fall. According to OSHA requirements, the warning line elevation should be between 34 and 39 inches (86.4 and 99.1 cm) to be effective.

Finally, the inadequate use problems include the use of a warning line on sloped roofs where it is not an adequate fall protection device or its use without the presence of a safety monitor to ensure workers will not expose themselves to falls from the unprotected edge. Further problems may occur if the safety monitoring system is not adequate:
1. the monitor is not competent on fall protection.
2. the monitor is not able to see all workers on the roof.
3. the monitor is not within oral contact of the workers.
4. the monitor has other functions which prevent him or her from supervising the workers.

4.2.1.2.2.7 Inadequate Controlled Access Zone (CAZ) Causes

A CAZ is an area where certain work (e.g., overhand bricklaying) may take place without the use of a guardrail system, personal fall arrest system, or safety net system. In general, a CAZ is the last safety option for the manager of a construction project. It does not eliminate the fall hazard, but attempts to control it by limiting the number of workers exposed to it. Only workers who have to perform a specific job within the zone are
granted access to it. Before they are allowed inside the CAZ, workers must have received training about the hazards they will face.

As with the previous devices, the potential causes of falls from a CAZ can be grouped into material, installation, and use problems. Material problems occur if the components are not up to OSHA standards either because they were inadequate from the start or they were worn out through use. To assure that the line will not break if a worker runs into it, it should have a minimum breaking strength of 200 pounds (0.88 kN).

Installation problems occur if the line is not properly erected. In order to control access to the area where leading edge or other operations are taking place, the zone shall be defined by a control line or other means to restrict access to it. Means other than control lines could be used to restrict access to a controlled zone. For example, a home builder may designate an upper level floor to be a CAZ and restrict entrance to the zone by placing a sign, a tape, a chain, or a gate on the stairway entrance to the floor. The same could be done for an upper floor where leading edge, overhand bricklaying, or pre-cast concrete erection is taking place, as long as all entrances to the floor are blocked and entrance to it is restricted to authorized workers.

Control lines are used to restrict access of unauthorized workers to the fall prone areas. The allowed distance from the edge to the line varies depending on the type edge operation being performed, as shown on Table 4.2.
<table>
<thead>
<tr>
<th>Type of Operation</th>
<th>Minimum Distance from Edge to Line</th>
<th>Maximum Distance from Edge to Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading Edge Work</td>
<td>6 ft (1.8 m)</td>
<td>25 ft (7.7 m)</td>
</tr>
<tr>
<td>Overhand Bricklaying and Related Work</td>
<td>10 ft (3.1 m)</td>
<td>15 ft (4.5 m)</td>
</tr>
<tr>
<td>Pre-cast Concrete Erection</td>
<td>6 ft (1.8 m)</td>
<td>60 ft (18 m)*</td>
</tr>
</tbody>
</table>

* 60 feet (18 m) or 1/2 length of member being erected ( whichever is smaller).

Table 4.2: Allowable distances from the edge to the line depending on the type of operation

The control line shall extend along the entire unprotected leading edge and be approximately parallel to it. The line shall be connected at each side to a wall or a guardrail system. In floors where no guardrails are in place, the CAZ must enclose all points of access, material handling, and storage areas.

If the line does not extend along the entire edge (e.g., overhand bricklaying):

1. The control line shall extend a distance large enough to enclose all authorized workers.
2. The line shall be parallel to the edge.
3. Additional lines shall be erected at each end to enclose the zone.
4. In edges where a guardrail is in place, but needs to be removed to allow overhand bricklaying or leading edge work, only the portion of the guardrail necessary for that day’s work shall be removed.
The line highest point (at stanchion) should not be higher than 45 inches (1.15 m) or 50 inches (1.3 m) for overhand bricklaying (i.e., so that materials can be moved underneath it). The line lowest point (at sag point) should not be lower than 39 inches (1 m). To increase its visibility, the line shall be flagged at intervals of 6 feet or less.

Inadequate use problems include cases where the CAZ is used in inadequate situations, without training the worker, without a safety monitoring system or with an inadequate safety monitoring system, or without developing a fall protection program. OSHA will allow the use of controlled access zones for the following situations:

1. Overhand bricklaying work (i.e., as long as the worker does not have to reach more than 10 inches below the working level to do the work).
2. Leading edge work.
3. Pre-cast concrete erection.
4. Residential construction.

However, the only option where the use of CAZs is specifically allowed instead of conventional fall protection systems is for overhand bricklaying work. In the other cases, the contractor must prove that the use of conventional fall protection systems is infeasible or the use of fall protection systems creates a greater hazard.

A major problem with controlled access zones is that they do not physically protect the worker from falling. Problems occur if the worker is not trained to recognize and react to fall hazards.

In addition, a safety monitoring system must be implemented to monitor the safety of the workers inside the CAZ. The lack of a monitor could enable falls to occur from the
CAZ area. Further, as with warning lines, problems may occur if the safety monitoring system is inadequate; such as in the following situations:

1. the monitor is not competent on fall protection.
2. the monitor is not able to see all workers on the roof.
3. the monitor is not within oral contact of the workers.
4. the monitor has other functions which prevent him or her from supervising the workers.

Further, it takes time for a worker to react to an instruction from the safety monitor; therefore, even if the system is operating as planned, there is a chance the warning may come too late.

Finally, controlled access zones can only be used under limited circumstances and they must be implemented as a part of a fall protection plan stating the reasons for their use, the locations in which they will be used, and the employees authorized to work on these areas.

4.2.1.3 Causes of Falls from a Roof

A roof is the exterior surface on the top of the building. Falls from a roof structure can occur from three different locations: the roof edge, skylights and roof openings, or through the roof (i.e., due to roof sheeting failure). Studies by OSHA indicate that the percentage of falls from each of these locations is about the same. There are two main kinds of roofing structures: steep or low-sloped roofs. Most of the roofs for residential
houses are pitched or steep-sloped to prevent snow accumulation. On the other hand, most roofs of commercial structures are low sloped.

For both types of roof structures, the worker is assumed to be supported by a roof sheeting component, which in turn is supported by a roof rafters component. Residential structures are assumed to be wood-framed; therefore, the roof sheeting is going to be plywood, supported by wood rafters. On the other hand, for a commercial roof structure the material components vary. For example, for a concrete shell roof, the roof sheeting component is made of concrete, and the rafter component will be the load bearing component provided to support the concrete roof.

Regardless of the roof structure and location, the support-related causes that may cause the support structure to collapse are divided into the triggering, enabling, and support causes related to the roof sheeting support component. Triggering causes include all the external factors that may act upon the roof and cause it to fail (e.g., strong wind impact, overload of materials on the roof, etc.). Enabling causes include any problems with the sheeting (e.g., inadequate strength, or water deteriorated plywood). Finally, support-related causes include problems with the roof rafters (i.e., enabling or triggering) or the structural component supporting them (i.e., rafter support-related).

In addition to the support causes that may result in the roof failure, the other basic causes (i.e., worker triggering and enabling) can play important roles in fall accidents, especially on sloped roofs. For example, any external impact on a worker is likely to cause the worker to lose balance and fall. The same applies to enabling problems; such as health problems, consumption of alcohol and drugs, and distractions. These could be enough to
affect the worker physical performance and judgment so as to cause him or her to lose control and fall. Finally, it should be noted that roof structures are exposed to the elements and the effect of environmental causes will be more pronounced (e.g., wind impact and slippery conditions due to rain, snow, etc.).

The roof structure and the location from which the fall may occur influence the type of fall safety device that can be used to control falls from roofs. Roof skylights should be guarded to protect workers from falling through them. The following devices can be used to guard them: a guardrail system, an opening cover, or a fall arrest system. The use of nets and catch platforms is unlikely due to space and practical considerations. The use of guardrails and covers is favored if the skylights appear on a flat roof, while fall arrest systems are more widely used in the case of a sloped roof.

For roof edges, the choice of protection devices depends on whether the roof is sloped or flat. If the roof is flat, the following devices may be used: a guardrail system, a safety net, a catch platform, or a warning line. The use of fall arrest systems is unlikely because they may require the installation of a temporary structure to act as an anchorage point or connector (catenary or horizontal lifeline). Any of the other previously named devices would be easier to implement. If a roof is pitched, the following devices are likely to be used: a guardrail system, a fall arrest system, a safety net, or a catch platform. The problems related to the inadequate use or installation of any of these safety devices is discussed on Lessons 5 through 12.

A final factor to be noted in the protection of roof edges is the case when there is a perimeter wall around the roof. If the wall is higher than or equal to 3.5 feet (1 m), no
additional fall protection has to be provided. In this case, the wall acts as a barrier which prevents the worker from falling.

4.2.1.4 Causes of Falls from Form Scaffoldingss

According to the Ohio Bureau of Workers’ Compensation (OBWC), a scaffolding is a temporary elevated platform for supporting employees, materials, or equipment. A sound scaffolding is essential to construction safety. There are two general types of scaffolding. An access scaffolding provides a safer and more comfortable elevated working platform for the support of workers and materials than a ladder does. In addition, a support scaffolding (or falsework) is a temporary structure used to support parts of permanent structures.

Most fall accidents occur from access scaffolds. According to OSHA’s standards, there are twenty-four different kinds of access scaffolding structures; the requirements for each are unique, and, consequently, the safety conditions and the structural problems of each scaffolding are different. In addition, access scaffoldings are subdivided into two primary categories: self-supporting and suspension scaffoldings. Self-supporting scaffoldings are structures made of one or more working platforms supported from below by brackets, poles, frames or similar supports. Examples of self-supporting scaffolds include: form, wood pole, tubular welded, mobile and tube and coupler scaffoldings. Suspension scaffoldings involve one or more working platforms suspended by ropes or other means from an overhead structure.
The causes of falls from form scaffoldings are representative of the causes of falls from scaffoldings (e.g., lack of fall protection); thus, in this study, form scaffolding structures and its related causes are studied. The worker enabling and triggering causes remain as discussed in Section 4.2.1.1; however, the support-related causes play an important role and are discussed in more detail.

Support-related causes include problems related to the structure or component supporting a worker while he or she performs a job. In the case of a form scaffolding, we assume that the worker is being supported by the planks and the brackets of the structure. There are two main types of support related problems: first, problems related to the planks or their support which lead to a worker fall without causing the structure or its components to collapse; and second, problems that due to their seriousness may cause the collapse of the whole support structure or one of its components, leading to a worker fall.

Included under the first group of support problems are those problems that may cause a worker fall without causing the support structure collapse: enabling, triggering, and support problems of the planks. Enabling problems include causes that may lead to the worker tripping: including: when the spacing between adjacent planks is too large, when the planks are overlapping one another (i.e., not flush), or when the planks used are defective and have chips or other problems that may cause a worker to trip. Furthermore, triggering problems related to the planks include environmental factors which may cause slippery conditions; such as: rain, snow, frost, and hail. In addition, triggering factors include impact-related factors which may not cause the structure to collapse, but may shake it, causing workers to lose their balance and fall, including: gust impact, material
impact, and equipment impact. Finally, the plank support problems event includes any problem with the brackets that may lead to the structure being sloped in any direction, causing workers to slip, such as when the connection of the brackets with the formwork is inadequate and the structure is tipped downward without collapsing, or when the brackets are not located at the same level; and, therefore, the planks are slopped in any lateral direction.

Among the problems that may cause the collapse of the structure or the component supporting the worker, we have plank enabling, plank triggering, and plank support-related problems. Under the enabling problems are the causes or combination of causes internal to the planks that may lead them to collapse. Among these we have the following: erection problems, if the planks are not bolted or nailed to the brackets underneath them or at least overlap the brackets by at least six inches (152 mm) over each end (i.e., in order for them to be adequately supported), or if the place where the plank ends abut each other is not located at the center of a bracket or on separate brackets (i.e., in order to prevent a plank from tipping over if the worker steps at its end); design problems, if the planks are not able to support at least four times the maximum intended load, if the planks cross-section is not at least 2x9 inches (51x229 mm), or if the planks length is not at most nine feet (2.7 m); and material problems, such as if the planks used are not scaffold grade or if the planks are defective due to weathering, assembling and disassembling, and corrosion, among other factors.

Planks triggering problems include the causes or combination of causes due to factors external to the planks and which may cause them to collapse. Among these we
have the following impact related factors: gust impact, equipment impact, or material impact.

As mentioned before, the planks are assumed to be supported by the brackets. Planks support problems includes bracket enabling, bracket triggering, and bracket support problems. Bracket enabling problems include problems internal to the brackets that may have caused their collapse and the collapse of all the components supported by them. Among the bracket enabling problems are erection problems, such as when the brackets are not firmly secured to the formwork, the ledger component of the bracket is not placed such that the largest section of the cross-section is perpendicular to the planks, or the bracket is not properly braced; design problems, such as when the design load used for the brackets is not adequate, the spacing between brackets is too large (it should not be more than 8 feet (2.4 m)), and the cross-sectional dimensions of the ledger, upright, and brace components of the bracket are too small. The ledger cross-section should be at least 2x6 inches (51x152 mm), the upright should be a 2x4 (51x102 mm) or larger plank, and the brace cross-section should be at least 2x6 inches (51x152 mm); and material problems, such as weathering, wear, corrosion, etc.

Bracket triggering problems include the causes or combination of causes due to factors external to the brackets and which may cause them to collapse. Among these factors, we have impact related factors which may lead to a bracket’s collapse, such as: gust impact, equipment impact, or material impact. Finally, the bracket support problems event includes any problems with the components supporting the brackets (i.e., formwork)
which may cause the structure’s collapse; including: enabling, triggering, and support with the formwork.

For a form scaffold, two types of conditioning causes are identified: one related to problems with general safety measures (e.g., poor work site maintenance) and the other related more specifically to problems with the fall protection/prevention safety measures in a site. If workers have to work on elevated structures like scaffoldings, fall protection is mandatory under most safety regulations. According to OSHA, guardrails should be installed on a scaffolding if its height is over four feet (1.219 m), because even at that height, a fall can bring serious injury to a worker. In addition, fall arrest systems could be used to prevent injuries to workers in the case of a fall. Either one of the two devices should be used at the site. The lack of both devices is considered a conditioning problem given that no protection is provided for the worker.

4.2.1.5 Causes of Falls from a Steel Beam.

Falls from beams during steel erection (e.g., during connection or installation) are a common cause of fatalities and injuries in construction. According to OSHA standards, “permanent floors shall be installed as the erection of structural members progresses, and there shall be no more than eight stories between the erection floor and the uppermost permanent floor.” In addition, a temporary but substantial floor deck should be maintained within two stories or 30 feet (9.15 m) of the erection floor. This regulation attempts to reduce the distance (i.e., to less than two stories) an iron worker would fall if a mishap were to occur. According to the same OSHA standard, section 1926.750 (b), if it
is not possible to install a temporary floor deck, and/or if the potential falling distance exceeds two stories or 25 feet (7.6 m), safety nets should be installed and maintained.

Because of the limited working area existing on the beam, there is little room for errors and the potential consequences of any external or worker related problem are increased. Further, as with roofs, these structures are exposed to the elements; therefore, environment-related causes can play a significant role on falls from them.

A large number of the falls from these component are due to the collapse of the steel frame. Here, the worker is assumed to be on a beam performing his or her job (e.g., connecting) and the beam is supported by the connection with the column. In this case, the causes of collapse may be enabling (e.g., poor beam design), triggering (e.g., due to crane impact), or support-related (i.e., internal or external problems related to the beam-column connection). For example, if during steel erection, the single bolt connections are used, the beam may roll over or fail causing the worker on it to fall. At least two bolts should be used to secure the beam at each end. This will prevent the beam from rolling over (i.e., turn on itself) when stepped on. Further, this will also reduce the likelihood that the steel structure will fail due to external factors (e.g., equipment impact).

Currently, it is recommended that whenever possible temporary working structures be used for the worker to do the erection work. For example, mobile scaffoldings can be used to do connection work. If these platforms cannot be used, the following systems could be used for the fall protection of a steel worker: fall arrest systems, safety nets, and catch platforms. Of these systems, the first two are most common. However, even they may not be easy to install, due to space or tie-up problems.
4.2.1.6 Causes of Falls from a Floor Hole.

The Code of Federal Regulations (CFR) defines a hole as a "void or gap 2 inches (5.1 cm) or more in its least dimension in a floor, roof or other walking/working surface and each employee on working surfaces shall be protected from falling through holes more than 6 feet (1.8 m) above lower levels."

The following are the hazards associated to floor holes: workers falling through the hole to a lower level surface, objects falling through the hole injuring workers or pedestrians at a lower level, or workers tripping on the unprotected hole causing a worker fall.

The use of a cover on the hole is the best way to eliminate all of these hazards. Other fall protection/prevention devices that can be used to guard a floor hole, include the following: a guardrail system, a safety net, or a fall arrest system. Due to their simplicity of installation and their effectiveness in eliminating the hazard, covers are the most commonly used protection device for holes. If the hole is going to be used to hoist materials into the floor or as an access point to the floor, a guardrail system will be used to prevent workers from falling into it. In this case, two sections of the guardrail may be removable, or an offset pathway could be used to prevent workers from walking into the hole.

The use of safety nets to guard holes is possible, but is not likely. If no construction operations require the hole to be open, a cover is the best way to protect the hole. If the hole must be open for hoisting or other construction operations, a safety net may obstruct these operations, thus a guardrail would be used. The use of a fall arrest
system is also possible, but is not as practical as other options which are easier to implement and do not put the burden of safety on the worker.

4.2.1.7 Causes of Falls from a Floor Edge.

A floor edge structural component includes any section of the floor perimeter (edge) which is open or not protected by a wall higher than 3.5 feet. This component only includes sections where a worker may fall toward the outside of the building (i.e., floor openings are excluded). This implies that any falls from this elevated component may cause serious (if not fatal) injuries to a worker.

In the case of a floor edge, the worker is assumed to be supported by the floor structure, which, in turn, is supported by floor joists. The collapse of a floor structure is unlikely; however, the collapse of the floor could be caused by enabling problems of the floor (design or construction problems), triggering problems (e.g., equipment or material impact on the floor), or support-related problems (e.g., problems affecting the floor joists).

Among the devices that may be used for floor edge fall protection/prevention are the following: a standard guardrail system, a fall arrest system, a safety net system, or a catch platform. Of these devices, the standard guardrail is the most commonly used device for floor edge fall protection. The safety net system is the second fall protection option considered if a guardrail system is not used due to operating reasons (e.g., the floor edge needs to be open to hoist materials to the floor). A catch platform erected near the floor edge may also be used depending on the elevation of the floor. In this case the catch
platform's guardrail will protect the worker from falling from the floor edge. Finally, fall arrest systems can also be used in areas not protected by a guardrail or safety net, such as hoisting areas in the floor.

4.2.1.8 Causes of Falls from Portable ladders

The following portable ladders are widely used on a construction site: step or self-standing, straight (regular), and extension. A step-ladder stands by itself, is not adjustable in length, and has a hinged back. A straight ladder is portable, is not adjustable in length, and consists of two bars or ropes joined to each other by steps. An extension ladder is portable and light-weight, with two or more sections that travel in guides or brackets.

In general, the basic causes of falls from a ladder are similar to those described on Section 4.2.1.1; however, as with steel beam work causes, their effect is significantly increased by the limited working surface (i.e., ladder step). For example, if a health problem attacks a worker while on a ladder, it may cause him or her to fall or may reduce the concentration or physical control required by the worker to avoid the fall. The same applies to triggering problems, where the smallest impact on the ladder or the worker may cause him or her to loose his or her balance and fall.

In addition to the basic causes previously discussed, there are other enabling and support-related causes that may cause falls from a portable ladder. Among the enabling causes are: improper use and improper selection. Improper use causes include cases when the worker has to over-reach to do his or her job. This situation occurs if the ladder is not high enough or is incorrectly placed. Overreaching may cause the worker to fall or the
ladder to topple. Further, experts recommend that a worker keep at least three contact points with the ladder at all times (either two feet and a hand, or two hands and a foot). This means that the worker has only one free hand to perform his or her job, unless he or she ties up. If a worker sits or stands on the top step of a step-ladder, he or she is not able to maintain the three contact points and is likely to fall.

Falls due to improper selection problems could be cause by the worker's attitude or training problems. They can be related to portable ladders whose load capacity is not enough for a given job. There are four types of portable ladders: Type 1A is an extra heavy duty ladder with a 300-pound (1.33 kN) capacity; Type 1 is a heavy-duty industrial ladder with a 250-pound (1.1 kN) capacity; Type 2 is a medium duty ladder with a 225-pound (1 kN) capacity; and, finally, Type 3 is a light-duty ladder with a 200-pound (888 N) capacity. The load capacity includes the weight of the worker and any tools or materials he or she is carrying.

Improper selection causes also include cases when the work must be performed around electric switches, outlets, or cables. For electrical work, metal ladders are good electricity conductors and should be avoided. If in contact with electricity, metal ladders will transfer it to the worker, causing him or her to fall. Wooden ladders should be used in this case.

As for the support-related causes they include the cases when the ladder is improperly placed. To prevent falls due to improper placement, the ground or surface where a ladder is standing should be thoroughly inspected. Loose or uneven ground and
slippery conditions should be avoided. In addition to a firm level base, other placement factors include the following [Hinze 1990]:

1. A step-ladder’s brace should be fully opened and locked before the worker steps on it.

2. An extension or straight ladder should be placed at around a 75° angle or pitch, so that the horizontal distance from the base of the ladder to the wall (or surface on which the ladder is sitting) is one-fourth of the vertical distance from the floor to the top of the wall.

3. An extension or straight ladder should be tied up, or otherwise secured (e.g., held by a coworker) to prevent it from being displaced. Once in place, the ladder should be tied a top to prevent lateral displacement. Further, The ladder’s safety shoes at its base should be deployed to prevent it from displacing horizontally.

4. An extension or straight ladder should be placed so that it extends about three feet (0.914 m) above the working surface the worker is trying to reach. That is, in order to allow the worker to maintain the three contact points with the ladder while reaching the working area.

5. The overlay of the sections in an extension ladder should be within standards. The worker should make sure of this, because if the overlay is less than that specified, the ladder may fail to support him or her and cause a fall. The overlays should be as follows: a 3 ft (0.915 m) overlap for a ladder up to 32 ft (9.76 m) long, a 4 ft (1.22 m) overlap for one up to 36 ft (10.98 m) long, a 5 ft (1.52 m) overlap for one up to 48 ft (14.64 m) long, and a 6 ft (1.83 m) overlap for one above 48 ft (14.64 m) long.
In addition to the basic causes, the following conditioning causes may contribute to falls from a ladder. For example, unless it is protected by barricades or guards, a ladder should not be placed in a passageway, driveway, doorway or any other area where it may be displaced by activities being conducted by any other workers. Further, before using a ladder, a worker should check for broken steps, corrosion, structural weaknesses, loose rails or side rails, loose connections, dents, and any other sign(s) that may indicate that it is not safe.

Finally, under normal conditions, no fall protection device is used with ladders; however, if the worker will have to use both hands to complete the job in hand, a fall arrest system (i.e., self-retracting line) could be used to tie-up a worker while he or she is on the ladder. The use of this device will also help free the worker’s hands so that he or she can perform his or her job more effectively.

4.2.1.9 Causes of Falls from a Wall Opening

A wall opening is defined as an opening at least 39 inches (1.0 m) in its least dimension in any wall or partition, and through which persons may fall more than 6 feet (1.8 m). An opening for elevator doors on an elevated floor is an example of a wall opening. In this case, a worker may fall more than six feet into the elevator shaft.

The support-related causes related to the collapse of the support structure are similar to those discussed for floor edge falls; thus, they are not discussed here again. For a wall opening, a standard guardrail system is the device most commonly used to guard the opening. However, devices like safety nets and catch platforms may achieve the same
results (unless space constraints restrict their use). Furthermore, fall arrest systems could also be used; however, other devices would be easier and more economical to implement.

4.2.1.10 Causes of Falls from a Top of Wall

When the worker is performing a job on the top edge of a wall, due to the limited working and walking surface, the main hazard workers face is that of falling to a lower level. The likelihood of a worker falling due to worker-related (e.g., intoxication or distraction) or external causes (e.g., environmental or impact causes) is greater due to the smaller surface area. The limited working area requires the worker to be in full mental and physical control, or else risk a fall. In addition, the effects of external events acting upon a worker in a limited working area may be more serious. For example, if a worker is hit, or exposed to environmental forces, it may be harder for him or her to maintain his or her balance.

As for the falls caused by the support structure collapse, they are related to the wall over which the worker is standing (i.e., wall enabling or wall triggering), or the beam assumed to be supporting the wall (i.e., beam enabling, beam triggering, or beam support-related). As mentioned in the scope and limitations (Chapter 1) of this project, these causes are not developed further, given that they rarely cause falls.

The number of devices that can be used for fall protection/prevention at the top of a wall component is limited to the following: fall arrest systems, catch platforms, and safety net systems. Of these, safety nets and catch platforms may be the easier to
implement. A fall arrest system could be implemented; however, the erection of a temporary anchorage structure (i.e., horizontal lifeline) might be required.

4.2.2 Causes of Falls from the Same Level

A ‘fall’ occurs when the worker loses his or her balance and fails to regain it. His or her body goes from an erect to a prone or semi-prone position. When walking, the body weight (i.e., center of gravity) is supported by the right or the left foot as one foot is moved in front of the other during the stride. This motion requires the walker to balance his or her body weight on the support foot. Anything that upsets this balance can cause a fall accident. A same level fall occurs when the fall starts and ends on the same working surface.

Compared to that for higher elevation falls, the frequency of falls on the same level is high in a construction setting that is full of hazards that may cause them. However, the severity of the injuries caused by same level falls is generally lower than that for higher elevation falls. In most cases, they result in minor injuries, such as sprains and strains.

All of the basic causes discussed in Section 4.2.1.1. can result in same level falls. The exception are the causes related to the support structure collapse which do not play a role in this kind of fall. However, tripping and slipping hazards are a major cause of these falls. Slipping hazards will be discussed on the next section. Trips can be due to the worker’s foot or leg contacting an unexpected obstruction or “on occasion, too much friction between the foot or footwear and the walking surface” [Ellis 1994]. The following are examples of tripping hazards: loose boards, protruding nails, holes, bend plates, open
drains, projecting machine parts, hoses and cables, pipe conduits above the working surface, boxes or materials stored on the working surface, tools left on the working surface, and unexpected level changes on the work surface (uneven walkways, bumps), among others.

All of these problems could be prevented with a good safety program which emphasizes good housekeeping practices, worker training, and planning to avoid those hazards (i.e., general safety problems).

4.2.3 Causes of Slips (not fall)

A slip is a temporary loss of balance resulting from a reduction or loss of friction between the worker and the supporting work area. It is "characterized by a sliding motion where the foot (shoe) loses traction with the walkway surface resulting in a loss of balance" [Szymusiak and Ryan 1982]. A slip can result in injuries such as a strained lower back if the worker is able to regain his or her balance. It can also become the cause of a fall accident whose consequences may range from major injuries to death.

When walking, the body weight is alternatively carried by the right or the left foot as one foot is moved in front of the other. Four distinct contact phases are identified in a normal walking stride [Lin et al. 1995]:

1. The landing phase when only the rear part of the foot (heel) contacts the floor.
2. The stationary phase when the foot is flat on the floor.
3. The take-off phase when only the front part of the foot (toes) touches the floor.
4. The swing phase when the foot is being moved forward.
Studies have shown that slips and falls occur when the smooth body weight transfer between feet is interrupted and the body is thrown off balance.

Slips may occur during the landing phase (i.e., the heel of the foot touches the walking surface), when the foot slides forward, causing the body’s backward motion or during the take-off phase (i.e., the toes of the foot touch the walking surface), when the foot slides backward, causing a forward motion of the body. In both cases, the frictional forces between the floor surface and the worker shoes is not large enough to resist and overcome the horizontal forces generated during the walking stride.

The coefficient of friction (COF) is used to evaluate the slip resistance of a surface given that it shows the magnitude of the frictional force acting between two surfaces. Two forms of COF are used toward that end: the static COF and the dynamic COF. In order to minimize potential slips, a currently accepted standard requires that the working surface should comply with the following minimum SCOF dry surface values obtained using a horizontal pull slip tester or a Brungraber device: 0.5 slip resistance in all areas (ASTM D2047), 0.6 resistance in walkways and level ramps, and 0.8 resistance in sloped ramps with a maximum slope of 1:12. These values do not consider the influence of the environment, the surface contaminants, the worker, and the shoe on a slip accident.

In addition to the roughness of the working surface, other factors that may contribute to the occurrence of slips, include:

1. Contaminants such as water can create hydroplaning or lubrication by reducing the contact between the shoe and the working surface.
2. The worker shoes. Walking involves the interaction between the shoe surface and the walking surface. The worker shoes should be slip resistant.

3. The work task being performed. The worker should be able to maintain his or her balance while performing the task at hand.

4. Worker training. Training should enable the worker to recognize the slip hazard, his or her physical limitations, and the measures he or she can take to avoid this kind of accident.

As for the conditioning causes that may contribute to slips, they are related to the items discussed on the general safety problems section. For example, housekeeping and working surface lighting. Workers should be trained to clean or remove spills, snow, or ice on the floor surface, or place barriers around them. The work area should be well lit. Poor lighting affects the worker's ability to detect unexpected changes or contaminants in the working surface.

4.3 Fault Tree Development

After studying and identifying all the potential causes of falls and slips, the second step in developing the fault tree structures for these events was the determination of the relationship among all of the causes. Finally, these relationships were organized into fault tree structures.

As mentioned before, the fault tree development starts with the determination of the top undesired event. In this study, this undesired event is a fall from an elevated component, a fall from the same level, or a slip. In this section, the fault trees for falls from
one of the elevated components (i.e., worker falls from a floor edge), falls from the same level, and slips are discussed in detail. The fault trees for falls from the other elevated structures will be included in Appendix B. The overall structure of these fault trees is similar to the one discussed in this section.

The structure of the models is based on a previous structure developed by Hadipriono [1992b] in an earlier study and later expanded in studies by Vargas [1993], Yoo [1994], and Hadipriono et al. [1995b]. The fault tree models included in this section are based on these previous studies and have been modified based on current literature and regulations, and new experts’ knowledge.

4.3.1 Fault Tree Model for the Worker Falls from a Floor Edge Event

The following fault tree model determines the basic causes of construction falls from a floor edge. The floor edge component includes any edge of the floor which is open or unprotected by a wall. In order to develop a fault tree for the elevated floor edge construction system, the elements acting in the system and their interaction must be considered. The elements include, the worker, the external events acting upon the worker, and the working environment (i.e., support component) in which the worker is performing his or her job. In this case, for the development of the Worker Falls from a Floor Edge fault tree, the following support components are defined: worker, floor, and joists. The worker is assumed to be supported the floor, which in turn, is supported by joists (Figure 4.1). The main focus is on the worker.
Within the fault tree, the codes used identify the events. These codes consist of a letter that indicates whether the event is an intermediate events (G), a basic cause (B) or a conditioning cause (C); and a unique numerical code used to separate and identify each event in the tree.

We start the fault tree development process by postulating the Worker Falls from a Floor Edge (GTOP) event as the top undesired event (Figure 4.2). There are two major groups of causes of falls from this structure: Worker Related Causes (G10) and Worker Support I (G11). The first type of causes (G10) includes all the cases in which the worker fall is due to any problem or combination of problems other than the collapse of the structure or the component supporting the worker. The second type of causes (G11) includes any cause that may lead to the collapse of the structure (or component) supporting the worker. It is assumed that the collapse of the component supporting the worker will also lead to the fall of the worker, regardless of any other conditions. This is the reason an XOR gate is used to relate events G10 and G11. If the structure collapses,
the cause of the worker fall is the structure failure; and, if the structure does not collapse, the cause(s) of the fall is/are under the Worker Related Causes event.

Event G11 which is directly related to the floor collapse is expanded into the Floor Enabling I (B20), Floor Triggering I (B21), and Floor Support I (G22) events. These events are related by using an OR gate because any one of them may cause the structure to collapse. The G22 event is developed further, using an OR gate, into the following problems related to the joists: Joists Enabling (B30), Joists Triggering (B31), and Joists Support (B32). As mentioned in Chapter I (i.e., scope and limitations), the collapse of the floor structure is uncommon; and, therefore all of these events are considered to be potential basic causes of fall. Enabling problems are internal to the component, triggering problems are caused by external factors acting upon the component (e.g., equipment impact), and support problems are related to the component immediately supporting the current one.

In contrast, the Worker Related Causes (G10) event contains all the causes or combinations thereof which are not related to the collapse of the support structure. This event could be caused either by the combination of worker related causes and safety problems in the site (G20), or worker related causes alone (G21). The XOR gate used to relate these events indicate the they are mutually exclusive events.

Under the Worker Combination (G20) event are the cases where the worker's fall is due to a combination of Worker Causes (G30) and Unsafe Conditions (G31). They are related by an inhibit gate to indicate that the presence of unsafe conditions in the floor edge before the basic event occurrence facilitated the worker's fall. In other words, the fall
may have not occurred had the safety conditions been adequate. The G30 event includes all the basic causes related to the worker (i.e., Worker Enabling I, Worker Triggering, and Worker Support II) and the G31 event includes all safety problems near the edge (i.e., fall safety and other general safety problems).

The Worker Enabling I (G40) intermediate event include problems internal to the worker. This gate is divided into Worker Attitude (G50), Worker Health I (G51), and Worker Skills (G52). Attitude problems include the following: Worker Alcohol I (B60), Worker Drugs I (B61), Worker Personality (B62), and Worker Distractions (Stress) (B63). Health problems include the following basic causes: Worker Acute I (B64), Worker Chronic I (B65), Worker Fatigue I (B66), and Worker Prescription Drugs I (B67). Finally, the skills event includes the problems related to Worker Training (B68), Worker Experience (B69), and Worker Aptitude (B610).

Furthermore, the Worker Triggering (G41) event includes all the external events acting on the worker, including: Worker Impact (G53), Worker Environmental Conditions (G54), or Worker Distractions (Surroundings) (B50). Impact related causes include the following: Worker Equipment Impact (B611), Worker Material Impact (B612), or Worker Other-Worker Impact (B613). Environmental conditions could cause falls due to Worker Distractions (G60), Worker Visibility (G61), Worker Gust Impact (B614), or Worker Extreme Heat (Dehydration) (B615). Both visibility and distraction problems may occur under the following conditions: Worker Rain (B70), Worker Hail (B71), Worker Snow (B72), or Worker Fog (B73). Additionally, Extreme Heat (B74) and Extreme Cold (B75) conditions may also affect the worker's concentration.
And, the Worker Support II (G42) intermediate event contains problems related to floor support. This event contains Floor Enabling II (G55) or Floor Triggering II (G56) problems. Enabling problems are related to the floor itself which may cause a worker to slip or trip, such as the following: Floor Holes (B616), Floor Sudden Level Changes (B617), Floor Obstacles (B618), Floor Excessive Slope (B619). The triggering problems include external factors that act upon the floor and make slips or trips likely, such as environmental factors (G62) and liquids or small materials that may cause slippery conditions, impact related factors (G63) that may cause the floor to tremble or shake and the worker to loose his or her balance and fall, and materials or tools left on the floor which may cause a worker to trip (G64).

On the other main branch, the Worker Specific (G21) intermediate event includes the cases when the worker may fall despite the presence of adequate safety measures, including the following cases: Worker Enabling II (G32), Worker Triggering (G41), or Worker Support II (G42). The triggering and support problems have already been discussed. Among the enabling causes which by themselves could cause the worker to fall are the cases when the worker has no mental or physical control, including: Worker Alcohol II (B40), Worker Drugs II (B41), Worker Acute II (B51), Worker Chronic II (B52), Worker Fatigue II (B53), or Worker Prescription Drugs II (B54). In this case, the drug, alcohol, and health problems are very serious and thus can cause the worker to collapse.

Unsafe conditions are classified into two types: first, those related to fall safety problems (G48) and those related to other general safety problems (C40). For a floor
edge, the following fall protection devices may be used: a guardrail system, a catch platform, a fall arrest system, a safety net system, or a controlled access zone. If none of these systems is used to guard the floor edge from falls, the lack of these devices in the structure is considered a conditioning cause which would facilitate the occurrence of a fall (C50). If one of these devices is installed but inadequately (G57), that will also be considered a conditioning cause of a fall. As discussed in the causes section, the device inadequacy can be due to installation, material, or use problems; and these problems vary depending on the device. For example, for the Inadequate Guardrail System (G65) event, inadequate installation (G70) problems include missing components (C80), inadequate post spacing (C81), inadequate rail elevation (C82), inadequate connections (C83), inadequate rail overhangs (C84), and inadequate access to hoist area (C85). Inadequate materials (G71) include two main problems: inadequate original component (C86) or excessive wear (C87). Finally, inadequate use (G72) problems include the following: temporary removal of wirerail (C88), removal of more than two guardrail sections protecting a hole (C89).
To be continued

Figure 4.2: Fault tree model for the "Worker Fall from a Floor Edge" event
Figure 4.2 (Continued)
Figure 4.2 (Continued)

To be continued
Figure 4.2 (Continued)
Figure 4.2 (Continued)
Figure 4.2 (Continued)

To be continued
Figure 4.2 (Continued)

To be continued
Figure 4.2 (Continued)
4.3.2 Fault Tree Model for the *Worker Falls from the Same Level* Event

In falls from the same level, the worker's fall starts and end on the same working surface. Therefore, the collapse of the supporting structure does not play a role in this kind of accident. Furthermore, as discussed before, the worker’s shoe may play an important role in the occurrence of slips which may lead to falls. Therefore, for the development of the fault tree structure for this accident, we assume that the worker is supported by the shoes, which are respectively supported by the floor or working surface (Figure 4.3).

![Diagram](image)

**Figure 4.3:** Support components used for the *Same Level Falls* fault tree

The top event of the tree is the Worker Falls from the Same Level event (GTOP). This event could occur due to a combination of worker causes and unsafe conditions (G10) or worker-related causes alone (G11).

Under the event G10 (i.e., combination), the worker-related causes (G20) could include enabling I (G40), triggering (G41), and support (G42) problems. The first two events will remain grouped as discussed on the previous section (i.e., the enabling gate
includes attitude, health, and skill problems; and the triggering gate includes impact, environmental, and distraction problems). As for the support problems they are classified into Shoe Enabling, Shoe Triggering, and Shoe Support. The first two are assumed to be basic causes. with the enabling representing the case when the shoes do not have slip resistant soles and the triggering the case of an external event actively acting upon the shoe (i.e. hitting). The Shoe Support event is further divided into Floor Enabling and Floor Triggering problems. The enabling event includes the following potential problems that could cause slips or trips: Floor Holes, Floor Sudden Level Changes, Floor Obstacles, Floor Excessive Slope. The triggering event includes external factors that cause slipping (i.e., environmental factors, water or other liquids on the floor, or small materials or objects on the floor), or tripping hazards (i.e., tools or materials left on the floor). Further, impact of materials or equipment on the floor may cause the floor to tremble or shake and the worker to lose his or her balance and fall.

In the case of same level falls, the unsafe conditions event is not related to fall protection problems, but general safety problems, such as Poor Housekeeping, Poor Overhead Protection, Poor Personal Protective Equipment, Poor Worker Training, and Poor Safety Policies.

The other branch of the tree, Worker Specific, includes the cases when the worker-related causes alone led to the fall accident. This event could occur due to certain enabling causes (i.e., alcohol use, drug use, and health problems), triggering, and support-related problems.
Figure 4.4. Fault tree model for the "Worker Fall from the Same Level" event
Figure 4.4 (Continued)

To be continued
Figure 4.4 (Continued)
Figure 4.4 (Continued)
4.3.3 Fault Tree Model for the Worker Slips (Not Fall) Event

This section includes the cases when the worker slips but is able to regain his or her balance before falling. The importance of this kind of event is that it may be an indication of the potential for more serious accidents (e.g., falls). As for same levels, the support components are assumed to be the worker’s shoes and the floor or working surface (Figure 4.5).

Figure 4.5: Support components used for the development of the Slips fault tree

A slip is by definition caused by the interaction between the floor and the worker’s shoe. If the friction between them is adequate, a slip will not occur. Therefore, a slip (not fall) accident will only occur when both a general safety problem occurs in combination with certain worker related (i.e., enabling, triggering, or support-related) problems. The worker enabling and triggering causes will remain as discussed before. The Worker Support causes will include Shoe Enabling (i.e., not slip resistant soles), Shoe Triggering (i.e., due to lateral impact on shoe), and Shoe Support (i.e., Floor Enabling and Floor Triggering). Floor Enabling includes problems innate to the floor which could cause slips; such as: low floor friction, sudden surface and friction changes, and excessively sloped
floors. Floor Triggering problems include external problems affecting the floor which could cause a worker to slip, such as: certain environmental factors, water or other liquids on the floor, or small materials or objects on the floor.
Figure 4.6: Fault tree model for the "Worker Slips" event

To be continued
To be continued
Figure 4.6 (Continued)
Figure 4.6 (Continued)
CHAPTER 5
AN EXPERT SYSTEM TO INVESTIGATE FALLS

5.1 Introduction

This chapter begins with a brief background about expert systems. Next, it discusses all the steps related to the development of an expert system module for investigating falls (see the branch highlighted in Figure 5.1), including the research methods used for the development of the expert system module for investigating falls (i.e., knowledge acquisition, knowledge representation, expert system development, and system testing and validation), the architecture of the system (i.e., knowledge base, inference engine, user interface, and external files interface facilities), and the methods of implementation for each of the system components.

The investigation module of the SAFETY FIRST program consists of ten different knowledge bases which have been developed based on the fault tree structures discussed on Chapter 4. The module consists of a knowledge base to investigate slips, one to investigate same level falls, and eight knowledge bases to investigate falls from the eight elevated components included in this study: roofs, form scaffolds, floor edges, floor openings, steel beams, portable ladders, wall openings, and tops of walls. It is expected that this module of the SAFETY FIRST program will be used by site and project
managers to investigate the causes of falls in their sites and implement appropriate measures to prevent the recurrence of this type of accident.

Figure 5.1: Program Structure (Fall Investigation Module)

5.2 Introduction to Expert Systems

Expert systems are a branch of the artificial intelligence (AI) field in computer science. Early efforts in AI dealt with the representation of non-numeric symbols and emulation of information processing, heuristic search, problem solving, and knowledge structure, among others. The following historical background of AI was obtained from Simon's *Expert Systems and Micros* [1985].

The firsts version of AI may be dated to 1936 when Alan Turing developed the general "Turing machine" which became the basis of the theory of computing. Later in 1943, the first electronic computer, Colossus, was developed at Bletchley. Taking
advantage of these advances, in later years, computers were used in several applications in which they exhibited human-like intelligence capability. On the other hand, these early machines could also be perceived as powerful calculators requiring instructions on what to do and without any real intelligence. By 1956, John McCarthy had developed the LISP (List Processing) language and the interest in the topic of "how to simulate human intelligence" was at its peak. This motivated the "Dartmouth conference" where the importance of the artificial intelligence field was recognized. In the years after the conference up until the 1970s, the only major progress in the area was the development of the general problem solver by Newell, Shaw, and Simon. At this point, AI scientists recognized that knowledge is an essential part of intelligence. They also recognized that the amount of knowledge a computer would have to store to have human-like intelligence was infinitely large. On the other hand, they also found that if the sector of expertise was more narrowly focused, computers could still be used to simulate human expertise. This more focused area of AI includes the systems known as "expert systems" and "knowledge-based systems."

Expert systems allow for the automation of solutions to problems which require heuristic human knowledge such as rules of thumb, judgments, intuition, or experience. Specifically, an expert system can be defined as "a computer program that relies on a body of knowledge to perform a somewhat difficult task usually performed only by a human expert. The principal power of an expert system is derived from the knowledge the system embodies rather than from search algorithms and specific reasoning methods. An expert
system successfully deals with problems for which clear algorithmic solutions do not exist” [Parsaye and Chignell 1988].

The objective of an expert system is to simulate the reasoning process of a human expert, so that if faced with the same problem in a specific area of study, both the human expert and the system would reach a similar conclusion. In order for an expert system to do that, it should contain a large enough base of knowledge so that, if given some information, it would be able to decide on the best solution to the problem. The knowledge stored in the system is mainly obtained from literature and experts through a knowledge acquisition process.

Many of the early expert systems were developed using computer languages like LISP (List Processing) and PROLOG (programming logic language); however, these programs required a great deal of computer programming knowledge in the field of AI. This made it difficult for professionals in other areas to develop expert systems. Furthermore, the implementation of a program with these languages meant the misuse of the programmer’s efforts, since facilities like help screens and forward and backward chaining inference mechanisms had to be developed from scratch for each system.

Nowadays, expert systems are developed with the help of expert system “shells” which can be regarded as “a reasoning system out of which all the knowledge has been emptied” [Parsaye and Chignell 1988]. An expert system is created once the base of knowledge about a specific domain has been coded and input into the shell. A good expert shell should provide the facilities to assist the developer in the creation of the knowledge base, contain an inference mechanism to control the reasoning process, and include a user
interface mechanism to support the users' consultation with the expert system by providing the users with explanations and conclusions. Other important factors in the expert system shell are the ease of translation from language into computer code, the flexibility of the program regarding the addition of new facts and rules, and the operating and interfacing time (speed to respond to users' commands).

Figure 5.2: General Architecture of Expert Systems [Cohn and Harris, 1992]
Figure 5.2 illustrates the typical architecture of an expert system [Cohn and Harris 1992]. It consists of a knowledge acquisition facility through which the knowledge engineer facilitates the acquisition of knowledge from human experts. This expertise consists of both heuristic knowledge and written definitional knowledge. A heuristic is a rule of thumb that allows the assignment of a value to or a judgment of a variable that would otherwise be unpredictable. On the other hand, definitional relationships are defined (or declared) by common agreement about how words are to be used [Harmon et al. 1990]; for example, OSHA safety codes. These types of knowledge are especially important because they are used by experts to reach decisions. Therefore, they are also the knowledge used by expert systems to handle complex and vaguely defined problems which conventional programs cannot handle easily.

This knowledge is stored in the system's knowledge base in the form of facts which describe aspects of the domain knowledge, and production rules which tell the system what information can be obtained from such facts. The knowledge code that controls its inference and search procedures is kept in an inference engine which, actually, is an algorithm that dynamically directs or controls the system when it searches its knowledge base [Harmon et al. 1990]. The inference mechanism (forward or backward chaining) combines the rules and facts in the knowledge base to reach a conclusion, much the same way experts reach a conclusion from available facts and previous experiences from dealing with similar problems. This separation of declarative and inference knowledge guarantees that the system can respond in a more flexible manner.
Furthermore, it lets the developer focus on getting the declarative knowledge (expert knowledge) that goes in the *knowledge base*, leaving the development of a specific search strategy to the *inference mechanism* (provided by expert shells).

In order for the system to reach a conclusion, it must have specific information about the domain problem (evidence). This information is obtained through the system’s *user’s interface*. In addition to obtaining information from the user, the user’s interface acts as the contact between the expert system and the user; therefore, through it the system’s user can get explanations regarding the information required, terms used, or conclusions obtained.

The use of expert systems has been very popular in all areas of study where human expertise and judgment are required to solve problems. For example, in the medical field, MYCIN was developed at Stanford University [Buchanan and Shortliffe 1984] to help physicians diagnose bacterial infections and prescribe treatments for them; INTERNIST was created to relate symptoms and diseases in internal medicine [Pople 1977], and so on. Expert systems have also been used in areas like chemistry (e.g., DENDRAL [Buchanan and Feigenbaum 1978]) and civil engineering (e.g., HI-RISE [Mather and Fenves 1985] and CONXPRT [AISC 1996]).

Other prototype expert systems developed in the Construction Engineering and Management Department at the Ohio State University include the EXPert ERECTion (EXPERECT) system, which can be used to determine alternative selection of bridge girder erection method [Sekii 1992], the Basement Failure Diagnosis Expert System (BAFDES) program which was developed to determine the causes of basement failures in
residential buildings in Ohio [Diaz 1992], and the Intelligent Traffic Evaluator for Prompt Incident Diagnosis (INTREPID) which was developed to speed up and improve the response to traffic accidents in the state of Ohio.

An expert system more closely related to the research topic of this report (construction falls safety) was developed by Hadipriono [1992a and 1992b]. In this study, a fault tree expert system for construction falls (FTES-FALL) was developed to simulate and investigate unintentional construction falls from floor openings. The fault tree models constructed were used as the knowledge structure for FTES-FALL. The knowledge base accommodates expertise obtained from experts and literature. A step-by-step process in developing the knowledge base was presented. Prompts were designed to lead the user to finding information/evidence needed to reach a conclusion. Parameters were identified and classified, leading to the establishment of frame-subframe relations. Each frame contains production rules that represent the expert knowledge. In addition, abundant help statements were provided to guide the user through the consultation process. The system was built using the Personal PCPlus Version 4.0 expert shell, which provided the features needed for the system development such as access to an interactive environment, an inference engine, external software, and graphic display ability. Despite these advantages, the system also had some limitations, namely, the use of the restrictive DOS environment by the PCPlus shell and the limited body of knowledge used for its development.
5.3 Research Methodology

The major tasks in the development of an expert system are knowledge acquisition, knowledge representation, expert system implementation, and system testing and validation. This section discusses the first two tasks of the development process of the expert system module to investigate the causes of falls. The last two tasks: system implementation and expert system validation, are discussed in Chapters 8 and 9 of this report.

5.3.1 Knowledge Acquisition

Knowledge acquisition is defined as “the process of eliciting and organizing the knowledge of an expert in a particular field (domain) so that this expertise can be coded into an expert system” [Brule and Blount 1989]. The challenges that come from attempting to capture human intelligence and transferring it to artificial representations that can be handled by computers are many. A great deal of research has been done in this area of study, resulting in the development of certain specific steps and techniques that can be used during the knowledge acquisition process to create a bond with the experts, to make them feel at ease, and to maximize the acquired knowledge [Brule and Blount 1989]. For example, when selecting the experts, their availability becomes one of the main factors to consider. If, due to time constraints or other considerations, the experts are not accessible for interviews, their knowledge is of limited use.

In general, there are three parties that play an important role in the success of a knowledge acquisition process: the knowledge elicitors, the knowledge programmers, and
the domain experts. The knowledge elicitors are in charge of interviewing the experts and eliciting their knowledge. The knowledge elicitors also plan the topics to be covered during the interviews and lead the flow of the conversation so as to maximize the amount of useful information obtained from the experts. The knowledge programmers, sometimes called software engineers, are in charge of obtaining the knowledge elicited from the experts and converting it into structures and codes that can be represented in the computer. Both the knowledge elictor and the software engineer are also known as knowledge engineers. The domain experts are those whose knowledge and experience in a given domain are paramount and stand above other knowledgeable people in the same domain, and whose expertise is to be incorporated into the knowledge base of an expert system. The experts also verify the applicability and correctness of the expert system and indicate whenever changes are necessary.

The knowledge acquisition process is generally divided into four phases: the preliminary, intermediate, advanced, and organization phases. The preliminary phase of the study includes activities like analyzing the project's feasibility; selecting the knowledge acquisition team; and choosing, contacting, and conducting a preliminary interview with the experts for the project. During the preliminary interview all of the parties of the project get to know each other and all of the ground rules for the process are discussed. This phase also involves the acquisition of general information about the subject from the experts and from literature reviews. The intermediate phase involves acquiring more specific information from the experts, reviewing this information, and after several interviews, creating a general representation of the experts' thought processes. The
advanced phase allows the knowledge engineer to refine the knowledge representation by going over the specific details which need to be clarified or which cause disagreement among the experts. Conflicting information or misunderstandings are usually settled by providing the experts with more specific explanations of the variables and parameters involved in the subject at hand. Finally, the organization phase acts as a link between the knowledge acquisition task and the fault tree development task. At this phase, the knowledge acquired is translated into a preliminary graphic representation model.

For the development of this system, the knowledge acquisition task involves acquiring experts' and literature knowledge on construction safety and construction falls. It also includes a review of the causes of falls from the same level, slips, and elevated components. Most of this knowledge is obtained from experts in the construction safety field.

5.3.1.1 Knowledge Acquisition for the Investigation Expert System

As mentioned in the previous section, the knowledge about falls safety was acquired from literature and expert interviews. Factual information about the causes of falls is rare. However, statistical reports regarding worker injuries and deaths due to falls help the industry identify problem areas where improvement should be made. The National Safety Council’s Accident Facts, the Bureau of Labor Statistics reports (e.g., Injuries Resulting from Falls from Elevations), and the National Institute for Occupational Safety and Health (NIOSH) reports (e.g., A Request for Assistance in Preventing Worker Injuries and Deaths Caused by Falls from Suspension Scaffolds and A Request for
Assistance in Preventing Worker Deaths and Injuries from Falls through Skylights and Roof Openings) are examples of such publications.

Another source of information are case studies of previous fall accidents from different structural components (e.g. roof, scaffolding structure, wall opening, floor opening, floor edge, steel beam, ladder, and tops of a wall). These studies contain information about the worker’s occupation at the time of the accidents, the type of accident (falls), the work surface from which the fall occurred, and a small description of the accident. The following are some of the reports published by OSHA’s Office of Statistical Studies and Analysis: Occupational Fatalities Related to Miscellaneous Working Surfaces as Found in Reports of OSHA Fatality Catastrophe Investigations, Occupational Fatalities Related to Ladders as Found in Reports of OSHA Fatality Catastrophe Investigations, and Occupational Fatalities related to Roofs, Ceilings and Floors as Found in Reports of OSHA Fatality Catastrophe Investigations, among others.

Code books, such as the 29 Code of Federal Regulations [1995], are the most suitable sources of information regarding the prevention of construction accidents. These code books contain the minimum safety requirements and equipment to be used to maintain a safe work site, which supervisors and managers should understand and apply while also educating their workers.

A final source of information regarding fall protection is Ellis's Introduction to Fall Protection [1994], published by the American Society of Safety Engineers, which provides the reader with a general review of fall protection and all the related issues that
construction companies and workers have to deal with in order to prevent falls from happening. This book introduces the user to the various issues involved in fall protection: types of falls and their classification, principles of fall protection, hazard analysis systems in order to recognize where and when protection is needed, steps to follow in order to organize a fall protection program, hazards associated with the use of fall protection equipment, and other issues.

As for the acquisition of experts' knowledge, the author of this report and his advisor acted as both knowledge elicitors and knowledge programmers for this project. The preliminary phase of the knowledge acquisition process for the project involved several activities, including reading articles and any other literature available on the subject, selecting the professionals who qualify as experts in the field, and finally, meeting the chosen experts and asking them to participate in our project.

For the preliminary selection of the experts, we considered the following points: the person had to be recognized by people in the industry as knowledgeable in the general area of safety and specifically, in the construction falls area, and the experts had to live in the Columbus vicinity. The latter is important since experts who live or work nearby could be easily reached for interviews and meetings. The final point to be considered was the amount of time the experts were willing to contribute to this project. All selected experts were willing to provide a reasonable amount of time to the project subject to their availability. The knowledge for this project is being acquired from the domain experts listed in Appendix A of this report. A brief summary of their background and work experience is included in same appendix.
After the experts were selected, we conducted the first interview with each of them. The main objective of this interview was to help the experts and the knowledge elicitors feel at ease with each other. During this interview, there was a preliminary discussion about the project, the characteristics of the research process, and the goals of the project. At that time, any questions the experts had regarding the project or the process required to develop the expert system were answered. Finally, during the interview, the knowledge elicitors and the experts decided on the best place and time to meet for future interviews and any other rules to be considered for future interviews (e.g., whether or not the expert(s) would allow the knowledge elicitor to record their conversations).

After the preliminary interviews, the objective was to focus the experts' attention on the subject matter (i.e., the intermediate phase). To do this, the authors created a questionnaire for the second interview with each of the experts. The questionnaire was developed with the objective of getting each expert to think about construction falls, first generally, and then, in more specific terms. The focus of this questionnaire was construction falls from high elevations. After these interviews, the knowledge acquired was reviewed and the topics of the next interviews were determined. These topics included areas that were not sufficiently explored in the previous interview, or which were not clear to the knowledge elicitors after review. At the end of the intermediate phase, we had developed preliminary fault tree models for all of the building components considered significant enough to be included in this project (e.g., a roof, a floor opening, etc.).
Finally, once the interview process had reached the advanced and organization phases, the interview topics concentrated on specific details regarding construction falls from the selected components. The experts also checked the preliminary fault trees, suggested changes to them (as needed), and any disagreements among the experts were resolved. For example, for a sloped roof, there was disagreement among the experts on whether or not devices like crawling boards, roofing brackets, and the so-called chicken ladders could prevent falls from happening. Some of them seemed to think so; while others did not. In this case, after further discussions with the experts, we agreed that those devices are useful tools that help the worker perform his or her job on a sloped roof, but they, by themselves, would not prevent the worker from falling and/or protect him or her from injuries if a fall occurs.

5.3.2 Knowledge Representation for the Investigation Expert System

The fault tree structures developed for falls from each of the elevated components, falls from the same level, and slips are the basic structures representing the causality relation among all the basic events (i.e., potential causes) that cause these accidents. Therefore, these representations provide a clear picture of the specific causes or combination of causes that may cause the top undesired event (i.e., fall or slip). However, in order to investigate the causes of a particular fall accident, experts also consider observable signs and other specific parameters and variables that may be used to infer whether a particular basic cause played a role in the accident.
For example, in order to determine whether the *inadequate original strength* of a guardrail component played a role in a fall from a floor edge, the expert will first examine if the guardrail system or one of its components failed under the worker impact (i.e., this is an observable fact). If the guardrail did not fail and was as installed, this cause can be discarded. If a component of the system did fail, then the expert will need to consider the materials the guardrail is made of and their cross sectional measures. These are also variables that can be obtained from the accident site by observation or measuring. Based on these measures and the material, the expert can conclude whether they were adequate (i.e., according to OSHA standards). If these measures were adequate, then the original strength cause can be eliminated. On the other hand, if these measures were inadequate (e.g., undersized component), then the expert could conclude that the *inadequate original strength* cause contributed to the fall accident.

This research proposes a decision structure that combines the causality relations depicted in the fault tree and the knowledge (i.e., signs and facts) needed to infer whether a specific cause played a role in the fall or slip being investigated. This decision structure uses a combination of decision tree and decision tables to determine the most likely cause of the accident being investigated. For brevity, in this section, only the decision structure developed for floor edge falls is discussed. The decision structures for the other elevated components falls, same level falls, and slips are included in Appendix C of this report.
5.3.2.1 Decision Structure for Floor Edge Falls Investigation

With a few exceptions, most falls in a construction site are due to a combination of basic causes and conditioning causes. The basic causes are related to the working structure, the worker, and the environmental conditions surrounding him or her at the time of the accident. Conditioning causes are related to safety problems existing in the site at the time of the accident.

In general, the system will investigate the basic causes and then the conditioning causes. First, if the fall is related to the collapse of the supporting structure, there is no need to investigate other basic or conditioning causes. The fall is caused by the structure collapse. This fact will be easily recognized upon a forensic visit to the site. Therefore, the first potential cause checked by the system is whether or not the fall is due to the floor collapse. If it is, the system will try to refine the conclusion further by investigating whether the cause of the floor collapse was due to a Floor Triggering (FEBas 1), Floor Enabling (FEBas 2), Joist Triggering (FEBas 3), Joist Enabling (FEBas 4), or Joist Support (FEBas 5) problems. If the user knows that the fall was due to the structure failure, but is not able to identify the specific cause of the failure, the system will indicate this fact in the conclusion FEBas 6.

If the floor collapse was not a factor in the fall, the system will proceed to investigate all of the other possible basic causes that may have lead to the fall accident from a floor edge. To begin this evaluation, the system will check if the cause was due to equipment impact or while avoiding such impact. If either of these is true, the system will check whether the equipment and worker operating areas were marked. If they were and
the worker was within the equipment operating area and the worker was not performing any jobs in that area, then part of the fall responsibility is the worker's (FEBas 12). If the worker was in the equipment operating area and he was performing a job on it, then the cause is related to his or her presence in the area, but the worker's responsibility is limited (FEBas 12). If the worker was not within the equipment operating area, an equipment internal failure (FEBas 8), an equipment external factor (FEBas 9), or the equipment operator (FEBas 10) may have contributed to the fall accident. Further, if the working areas were not marked, then this is a contributing factor to the fall (FEBas 7). Other factors that may have played a role in the accident are the following: poor visibility (FEBas 51), worker distracted (FEBas 52, FEBas 53, and FEBas 54), and worker experience and training (FEBas 55).

If the fall was not due to equipment impact, the system will check if there were working surfaces above the working surface from which the fall occurred or material was being moved above it. If either of these is true, the system will check if the fall was due to falling materials impact or occurred while avoiding such impact. Regarding this cause, the following are the significant factors: were the overhead working surfaces protected with toeboards or barriers to prevent objects from falling from them? (FEBas 13). was adequate overhead protection provided? (FEBas 14), and did the falling material hit the worker on the head? If the worker was hit on the head, two more factors are considered: was a hard hat worn by the worker at the time of the accident? and was a hard hat provided to the worker? If a hard hat was worn, the system will go on to evaluate other potential enabling problems. If it was not then a contributing factor to the fall is that the

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worker did not use the hard hat provided (FEBas 15) or he or she was not provided with a
hard hat (FEBas 16).

If a basic cause has not been found, the system will check next whether or not the
cause of fall was due to another worker hitting or tripping the worker, another worker
hitting the worker with a tool or material he or she was carrying, or occurred while
avoiding such impact. If this was the cause of the fall, the system will ask the user to
indicate if both workers were supposed to be on the work area (FEBas 17). If they were
not, then the worker who was outside his or her work area was one of the factors leading
to the fall accident (FEBas 18 and FEBas 19).

If the fall was not due to an impact-related problem and an electric power source
existed in the floor edge surroundings, then the system will check if contact with it caused
the fall (FEBas 20). If it was not, the system will check if the working surface from which
the fall occurred was exposed to weather, then the system will check if any weather
related factor led to the fall by hitting the worker and directly causing the fall (if there
were extremely gusty or hail conditions {FEBas 21 or FEBas 22}), by causing the worker
to slip (if there was rain, or snow on the day of the accident {FEBas 23 and FEBas 24}),
or by causing the worker to collapse due to dehydration (if hot conditions were
predominant at the time of the accident {FEBas 25}).

Furthermore, if slip hazards like small materials such as gravel are present on the
floor (FEBas 26 and FEBas 27), liquid substances (FEBas 28 and FEBas 29), or
excessively sloped surfaces (FEBas 30 and FEBas 31) occurred on the floor, then the
system will ask the user whether slipping was the primary cause of the fall. If it was, then
it will check the safety measures implemented (if any) regarding these hazards. If no safety cautions were implemented, then their absence is a contributing factor to the accident.

If the worker did not slip, the system will check if tripping hazards such as sudden changes in elevation (FEBas 32 and FEBas 33), floor holes (FEBas 34 and FEBas 35), objects protruding on the floor (FEBas 36 and FEBas 37), or tools or materials left on the floor (FEBas 38 and FEBas 39) were present in the site, the system will ask whether they caused the worker to trip. If the answer is yes, these conditions are the basic cause of the fall, even if the proper cautions have been taken to reduce their occurrence.

If none of the factors above led to the fall, then the system will check for the possible worker enabling causes that may have led to the fall. Health problems can cause a worker to collapse or lose control. These problems could be chronic (e.g., the worker had an epilepsy attack or any other disease that may have caused him or her to faint or lose physical control of his or her body {FEBas 40}) or acute (e.g., the worker had a heart attack {FEBas 41}). On the other hand, the worker may have collapsed, lost control, or acted irrationally due to his or her being intoxicated with alcohol (FEBas 42) or drugs (FEBas 43). Finally, the worker may have also been drowsy or not as alert as usual due to his or her taking an over-the-counter drug such as a cold medicine (FEBas 44).

In addition, the worker may have failed to notice the fall hazard or that he or she was getting too close to the floor edge due to poor visibility (FEBas 45), his or her being distracted (i.e., due to personal problems {FEBas 48}, extreme weather conditions {FEBas 46}, or an occurrence on the working area surroundings {FEBas 47}). Another factor considered is whether the worker followed orders well and behaved reasonably
(FEBas 49) in the site without taking unnecessary risks (i.e., acting recklessly). Finally the worker's experience and training are important in allowing him or her to recognize hazards and avoid them. Therefore, the lack of any of these may be a considerable factor in a fall accident (FEBas 50).

After examining the potential basic causes of the fall, the system will proceed to examine the potential conditioning causes of falls related to the lack of or inadequate fall protection. The system will proceed to ask whether or not there was any fall protection device guarding the floor edge or protecting the worker from falls. If the answer to this question is "no," then such a problem could be considered a conditioning cause of the fall (Cond 1). Unless the floor is already guarded by a perimeter wall 42 in (1.1 m) or higher. On the other hand, if the answer to the question is "yes," then the system will ask the user to select the fall safety devices used on the floor edge at the time of the fall and proceed to analyze their adequacy.

The following fall protection devices have been deemed adequate to protect the worker around a floor edge: a standard guardrail, a catch platform, a fall arrest system, a safety net system, and a Controlled Access Zone (CAZ). These devices are analyzed in the order listed, which is also the order in which they are preferred or used in construction sites. Once the user has indicated that a fall protection/prevention device was being used in the site, the system will check if inadequate material, inadequate installation, or inadequate use problems played a role in the fall accident.

If more than one safety device was being used at the edge from which the fall occurred, the system will analyze all the devices used. However, there are some limitations
in the combination of devices that may be used at the same time. The guardrail and catch
platform systems cannot be selected at the same time given that they perform the same
function (i.e., the catch platform's guardrail acts as a fall protection system). Similarly, a
catch platform and a safety net cannot be erected to protect the same floor edge due to
space limitations. The controlled access zone can only be used when none of the other
devices can be used and therefore, if this device is used, then none of the others is chosen.
Finally, if the other device option is chosen, the system assumes that none of the other
options provided apply. These constraints are reflected in the decision structure
developed.

Therefore, once the user has indicated that a fall protection or prevention device
was being used in the site, the system will check if that system is a guardrail; if it is, then
the system will proceed to evaluate its adequacy. If it is not, then it will check whether the
device installed is a catch platform. If the answer is "yes," the system will evaluate its
adequacy, otherwise it will go on to the fall arrest system and so on until the CAZ is
reached.

If a guardrail system was installed, then the system will proceed to analyze it. In
order to reduce the search space, the first question asked of the user is whether any of the
guardrail's components failed under the impact from the falling worker. If it did, the
system will evaluate problems related to inadequate original material or worn out
materials, inadequate component connections or installation problems that could
contribute to the system failure (e.g., post spacing is larger than 8 feet). If none of the
guardrail components failed and the system is as installed, the program will start to
evaluate installation and use problems. Therefore, the first question asked of the user is whether the guardrail's top rail failed under the impact of the falling worker. If it did, depending on the rail material, the system will check its cross-section to determine whether its original strength is up to standards. If the material used to build the guardrail is wood, the cross-sectional measures of the top rail should be at least 2 x 4 inches (50 x 100 mm). If the size of any of these component sections is smaller than the one specified, the undersized component of the system is not strong enough to support the worker impact (Cond 2). All of the possible decisions are depicted in Table 5.1.

If the material used to build the guardrail is pipe (Table 5.2), then the diameter of the top rail cross section should be at least 1.5 inches (40 mm). If this diameter is less than that, then the top rail's strength will be inadequate, contributing to its failure.

Further, if the top rail is made of L-shaped structural steel, then its cross section should be at least 2x2x0.375 inches (50x50x11 mm) in order to be strong enough to support a worker impact load and prevent him from falling. This lack of strength, if present, will be considered the conditioning cause of the rail failure (Cond 4) and may occur in the different forms depicted in Table 5.3.

If the material used for the top rail is wire rope whose diameter is larger or equal to 0.25 in (6 mm), then we know that this material complies with the strength standards set by OSHA and so the system will go on to investigate whether material fatigue or wear played a role in the rail's failure. Otherwise, the conditioning cause of the failure would be the use of inadequate strength material (Cond 5). Furthermore, if the materials used for the rails are made up of steel or plastic bands, it is already known that these materials are
too brittle and not adequate for fall protection; therefore, the system will conclude that their use is a problem (Cond 6).

If none of the previously named materials was the one used for the top rail, the user is allowed to indicate the material used and determine if it complies with the 200 pound (890 N) strength requirement (Cond 7).

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
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<tr>
<td>2 inches (50 mm)</td>
<td>&lt;4 inches (&lt;100 mm)</td>
<td>Cond 2</td>
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<tr>
<td>&lt;2 inches (&lt;50 mm)</td>
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<td>Cond 2</td>
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<td>&gt;2 inches (&gt;50 mm)</td>
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<tr>
<td>&gt;2 inches (&gt;50 mm)</td>
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<td>Cond 2</td>
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<tr>
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</tr>
</tbody>
</table>

Table 5.1: Decision table for wood top rail cross sections

<table>
<thead>
<tr>
<th>Diameter (In)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt;1.5 inches (&lt;40 mm)</td>
<td>Cond 3</td>
</tr>
<tr>
<td>&gt;1.5 inches (&gt;40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 5.2: Decision table for pipe top rail diameter

If the original material strength was not a factor in causing the top rail failure, the system will go on to evaluate whether the material used showed signs of fatigue or wear (e.g., rust, corrosion, cracks). If it did, this factor will be considered the specific
conditioning cause that caused the rail failure (Cond 8). Otherwise, the system will check if the spacing between the guardrail posts was larger than 8 feet (2.4 m). If this was the case, the excessive spacing of the posts would reduce the lateral support on the rail, increase sagging, and reduce the rail’s load bearing strength (Cond 9). Otherwise, the system will conclude that the top rail’s failure was a conditioning cause of the fall and was not able to find any specific problem that could have caused this failure (Cond 10).

If the failing component was the mid rail, the system will follow the same investigating process. First, it will investigate the original material strength of the mid rail, as follows: wood should have a minimum cross-section of 1x6 in. (25x150 mm) (Table 5.4, Cond 11), pipe should have a minimum diameter equal to 1.5 in. (40 mm) (Table 5.5, Cond 12), L-shaped structural steel should have a minimum cross-section equal to 2x2x0.375 in. (50x50x11 mm) (Table 5.6, Cond 13), wire rope should have a minimum diameter of 0.25 in. (6 mm) (Cond 14), steel and plastic bands are illegal (Cond 15), and any other material should be able to withstand a 150 pound (666 N) load (Cond 16). Second, the system will check for material wear (Cond 17) and post spacing (Cond 18). Third, if no specific conditioning cause is found by the system, it will conclude that the mid rail failure was the conditioning cause of the fall but no specific material or installation problem was found with it (Cond 19).
### Table 5.3: Decision table for L-shaped steel top rails

<table>
<thead>
<tr>
<th>Width</th>
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<th>Conclusion</th>
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</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
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<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
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<td>Cond 3</td>
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<td>2 inches (50 mm)</td>
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<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
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<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
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<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
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<td>Cond 3</td>
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<tr>
<td>&lt; 2 inches (50 mm)</td>
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<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<td>Cond 3</td>
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<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
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<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 3</td>
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<td>Cond 3</td>
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<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
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</table>

Next, if the failing component was an intermediate vertical component, a screen, or a panel, the system will proceed to check if it complied with the 150 pound load bearing capacity (Cond 20), or was worn out (Cond 21). If none of these applies, the conclusion
will be limited to identifying the component's failure as the general conditioning cause of the fall (Cond 22).

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch (25 mm)</td>
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<tr>
<td>1 inch (25 mm)</td>
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<tr>
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<td>o.k.</td>
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</tbody>
</table>

Table 5.4: Decision table for wood mid-rail cross section

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<th>Conclusion</th>
</tr>
</thead>
<tbody>
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<td>Cond 12</td>
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<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 5.5: Decision table for pipe mid rail diameter

If the guardrail posts failed, the system will investigate the original material strength: wood (Table 5.9, Cond 23), pipe (Table 5.10, Cond 24), L-shaped structural steel (Table 5.11, Cond 25), and other material (Cond 26). The material cross-sections required for the posts are identical to those required for top rails. Next the system will check for wear (Cond 27). Finally, the post failure (Cond 28) will be the conditioning cause if no specific problem is identified.
<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
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<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
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<td>Cond 13</td>
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<td>&lt; 2 inches (50 mm)</td>
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<td>Cond 13</td>
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<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (1 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (1 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (1 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 13</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (1 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 5.6: Decision table for L-shaped steel mid rails

Further, if the failing guardrail component is the toe board, the system will investigate strength (Cond 29), wear (Cond 30), and the bracing or lateral support of the
board (Cond 31). Conditioning cause 32 will indicate the component failure as a contributing factor to the fall.

Finally, if the system’s failure was not caused by specific material failures, the program will investigate the connections between the rails and the posts (Cond 33 and Cond 34) and the posts and the floor (Cond 35 and Cond 36).

If the guardrail failure did not play a role in the accident, the system will investigate if installation problems could have contributed to it. First, the system will check if the worker toppled (i.e., fell) over the guardrail. If it did, the system will check if the top rail was missing (Cond 37), the height of the top rail was below 39 inches (1020 mm) (Cond 38), or the post spacing was larger than 8 feet (2.4 m) causing the rails to sag (Cond 39). If no problem is found, the program will conclude that the guardrail did not contribute to the fall and go to evaluate any other fall protection device used in the floor edge (if any) or reach its final conclusion.

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 23</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>Cond 23</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 23</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>Cond 23</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 23</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 5.7: Decision table for wood post cross sections
### Diameter (In)

<table>
<thead>
<tr>
<th>Diameter (In)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt; 40 mm)</td>
<td>Cond 24</td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 5.8: Decision table for pipe posts diameter

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 25</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 25</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 25</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 25</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 25</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 25</td>
</tr>
</tbody>
</table>

Table 5.9: Decision table for L-shaped steel posts
If the worker fell through an area below the top rail, the system will determine if the mid rail or intermediate guard was missing (Cond 40), the toe board was missing (Cond 41), the guardrail had excessively large unprotected areas either between the top and mid rails or between the mid rail and the floor or toe board (Table 5.10—Cond 41, Cond 42, and Cond 43), or the post spacing was larger than 8 feet (2.4 m) and the mid rail sag (Cond 44). Otherwise, the guardrail system will be determined to be sound.

If the user of the expert system is not able to indicate whether the worker fell from above or below the top rail (i.e., there were no eye witnesses of the accident), the system will still try to evaluate if the guardrail installed was adequate; including whether there were guardrail components missing (Table 5.11) and what the guardrail rail elevations were (Table 5.10).

<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>o. k.</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&gt; 21 +/- 3 inches (&gt; 550 +/- 40 mm)</td>
<td>Cond 42</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&lt; 21 +/- 3 inches (&lt; 550 +/- 40 mm)</td>
<td>Cond 43</td>
</tr>
<tr>
<td>&gt; 42 +/- 3 inches (&gt; 1100 +/- 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>Cond 42</td>
</tr>
<tr>
<td>&gt; 42 +/- 3 inches (&gt; 1100 +/- 80 mm)</td>
<td>&gt; 21 +/- 3 inches (&gt; 550 +/- 40 mm)</td>
<td>Cond 43</td>
</tr>
<tr>
<td>&gt; 42 +/- 3 inches (&gt; 1100 +/- 80 mm)</td>
<td>&lt; 21 +/- 3 inches (&lt; 550 +/- 40 mm)</td>
<td>Cond 43</td>
</tr>
<tr>
<td>&lt; 42 +/- 3 inches (&lt; 1100 +/- 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>Cond 41</td>
</tr>
<tr>
<td>&lt; 42 +/- 3 inches (&lt; 1100 +/- 80 mm)</td>
<td>&gt; 21 +/- 3 inches (&gt; 550 +/- 40 mm)</td>
<td>Cond 41</td>
</tr>
<tr>
<td>&lt; 42 +/- 3 inches (&lt; 1100 +/- 80 mm)</td>
<td>&lt; 21 +/- 3 inches (&lt; 550 +/- 40 mm)</td>
<td>Cond 41</td>
</tr>
</tbody>
</table>

Table 5.10: Decision table for guardrail elevations

If no problem is found, the program will evaluate if inadequate use causes could have contributed to the fall. The wire rail was temporarily removed at the time of the fall.
The worker walked into a loading area and fell. If the worker intentionally entered the area where he or she was not performing a job, then that would be the cause (Cond 51). If the worker accidentally walked into the loading zone (i.e., access to the zone was not controlled with a gate or an offset rail—Cond 52). The worker was performing a job inside the loading zone and no other fall protection device was used to control fall hazards (Cond 53). After this, the guardrail evaluation will be completed and the system will proceed to evaluate either another safety device (if more than one fall protection device was being used to guard the floor edge) or reach its final conclusion.

If the fall protection device installed is a catch platform (i.e., scaffold), the system will start by investigating whether the worker fell through the opening between the floor edge and the inner edge of the catch platform (Cond 54). This distance should be smaller than 1 foot (304 mm).

Next, the system will inquire regarding the potential collapse of the scaffold structure or one of its components, causing the worker to fall. If this was the case, the system will attempt to determine the specific cause of the collapse: floor enabling (Cond 55), floor triggering (Cond 56), or floor support-related (Cond 57). Enabling problems may include plank wear and inadequate strength (e.g., they are not scaffold grade, inadequate cross sections, etc.). Triggering problems are due to external factors acting upon the floor planks. Finally, support problems are related to the failure of any of the structural components supporting the planks. If the user is not able to specify the specific problem, the general conditioning cause will be the structure failure (Cond 58).
<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Posts</th>
<th>Toe Board</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>Cond 45, Cond 47,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cond 48</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>Cond 46, Cond 47,</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>Cond 48</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>Cond 45, Cond 47</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>Cond 45, Cond 48</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
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<td>Cond 46, Cond 47</td>
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<tr>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>Cond 46, Cond 48</td>
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<td></td>
<td></td>
<td>Cond 47, Cond 48</td>
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<td></td>
<td>Cond 46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Cond 47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Cond 48</td>
</tr>
</tbody>
</table>

Table 5.11: Decision table for guardrail components missing

If no problem has been identified, the system will proceed to determine whether the fall accident occurred from a side of the catch platform which was not protected by a guardrail system. If this was the case, the lack of guardrail would be a conditioning cause of the fall (Cond 59). Further, the program will investigate if the scaffold had a guardrail system installed to prevent falls. If it did not, that would be the conditioning cause of the fall (Cond 60) given that the catch platform is intended to perform the functions a guardrail system would. Otherwise, the next step in the investigation process is to evaluate the catch platform’s guardrail. As with the guardrail system, the program will investigate if
any of the components or connections of the system failed or there were any installation problems that contributed to the fall accident. Given that the factors investigated are similar to those in a guardrail system, they will not be discussed again here. However, they are portrayed in Figure 5.3. and Tables 5.12 to 5.22.

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 61</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 61</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 61</td>
</tr>
</tbody>
</table>

Table 5.12: Decision table for a wood top rail cross sections of a Catch Platform

<table>
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<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch (25 mm)</td>
<td>6 inches (150 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>1 inch (25 mm)</td>
<td>&lt; 6 inches (&lt; 150 mm)</td>
<td>Cond 68</td>
</tr>
<tr>
<td>&lt; 1 inch (&lt; 25 mm)</td>
<td>6 inches (150 mm)</td>
<td>Cond 68</td>
</tr>
<tr>
<td>&lt; 1 inch (&lt; 25 mm)</td>
<td>&lt; 6 inches (&lt; 150 mm)</td>
<td>Cond 68</td>
</tr>
<tr>
<td>&gt; 1 inch (&gt; 25 mm)</td>
<td>6 inches (150 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 1 inch (&gt; 25 mm)</td>
<td>&lt; 6 inches (&lt; 150 mm)</td>
<td>Cond 68</td>
</tr>
</tbody>
</table>

Table 5.15: Decision table for a wood mid-rail cross section of a Catch Platform
### Table 5.13: Decision table for a pipe top rail diameter of a Catch Platform

<table>
<thead>
<tr>
<th>Diameter (In)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt;40 mm)</td>
<td>Cond 62</td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt;40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 5.14: Decision table for L-shaped steel top rails of a Catch Platform

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
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<td>&gt; 0.375 inches (11 mm)</td>
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</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
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<td>&lt; 2 inches (50 mm)</td>
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<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
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<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 63</td>
</tr>
<tr>
<td>Diameter (In)</td>
<td>Conclusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt; 40 mm)</td>
<td>Cond 69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.16: Decision table for a pipe mid rail diameter of a Catch Platform

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 70</td>
</tr>
</tbody>
</table>

Table 5.17: Decision table for L-shaped steel mid rail of a Catch Platform

204
### Table 5.18: Decision table for wood post cross sections of a Catch Platform

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Cond 75</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>Cond 75</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>Cond 75</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

### Table 5.19: Decision table for pipe posts diameter of a Catch Platform

<table>
<thead>
<tr>
<th>Diameter (In)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt; 40 mm)</td>
<td>Cond 76</td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

### Table 5.21: Decision table for guardrail elevations of Catch Platform

<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Cond 95</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Cond 95</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Cond 96</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Cond 94</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Cond 94</td>
</tr>
</tbody>
</table>

Table 5.18: Decision table for wood post cross sections of a Catch Platform

Table 5.19: Decision table for pipe posts diameter of a Catch Platform

Table 5.21: Decision table for guardrail elevations of Catch Platform

205
<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Cond 77</td>
</tr>
</tbody>
</table>

Table 5.20: Decision table for L-shaped steel posts of a Catch Platform
Next, the system will check if a fall arrest system was used. If it was, the first factor the program will check is whether the worker was using it. If he or she was not attached to the system that would be the conditioning cause of a fall (Cond 102). Fall arrest systems can be grouped into the following: vertical lifeline and lanyard, horizontal lifeline, and self-retracting lines. The system will analyze the one that is being used in the site. For a vertical lifeline and lanyard, the expert system will first investigate if any of the components (anchorage, vertical lifeline, snap hook, deering or connector, or harness) of

<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Posts</th>
<th>Toe Board</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>Cond 97, Cond 99, Cond 100</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>Cond 98, Cond 99, Cond 100</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>Cond 97, Cond 99</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Cond 97, Cond 100</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>Cond 98, Cond 99</td>
</tr>
<tr>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>Cond 98, Cond 100</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Cond 99, Cond 100</td>
</tr>
<tr>
<td>x</td>
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<td></td>
<td></td>
<td>Cond 97</td>
</tr>
<tr>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>Cond 98</td>
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<tr>
<td></td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>Cond 100</td>
</tr>
</tbody>
</table>

Table 5.22: Decision table for guardrail components missing of a Catch Platform
the device failed. The anchorage point, in order to be adequate, should be able to withstand a minimum load of 5000 pound (22.2 kN) per employee attached (Cond 104). Fatigue or wear may reduce its strength (Cond 105). In general, the failure of the anchorage point is indicated by conditioning cause 106. Next, if the failing component is the vertical lifeline, the system will check its strength (it should be able to withstand a 5000 pound load with only one employee attached, except for elevator shaft work), its wear and fatigue (Cond 108), and conditions which may reduce its load bearing capacity (Table 5.23).

<table>
<thead>
<tr>
<th>Lifeline Conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using a knot</td>
<td>Cond 109</td>
</tr>
<tr>
<td>Tied to structural steel I or H beam</td>
<td>Cond 110</td>
</tr>
<tr>
<td>Passes around or over rough or sharp surfaces</td>
<td>Cond 111</td>
</tr>
</tbody>
</table>

Table 5.23: Decision table for lifeline strength reduction conditions

In the same manner, a lanyard failure (Cond 118) could be due to inadequate strength (i.e., less than 5000 pounds) (Cond 113), wear and fatigue (Cond 114), and special conditions (Table 5.24).

<table>
<thead>
<tr>
<th>Lanyard Conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using a knot</td>
<td>Cond 115</td>
</tr>
<tr>
<td>Tied to structural steel I or H beam</td>
<td>Cond 116</td>
</tr>
<tr>
<td>Passes around or over rough or sharp surfaces</td>
<td>Cond 117</td>
</tr>
</tbody>
</table>

Table 5.24: Decision table for lanyard strength reduction conditions

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Further, if the failing component is a snap hook (Cond 122) the system will again check for strength (Cond 119) and fatigue problems (Cond 120). In addition, it will check if the snap hook used is non-locking (Cond 121), their use is considered a conditioning cause of fall given that their use for fall arrest systems is currently illegal.

Finally, if a deering, a connector, or the body harness of the fall arrest system failed, then the expert system will again check if they could withstand a 5000 pound load (22.2 kN) or showed signs of fatigue or wear (Cond 123 to 128).

If the failure of the vertical fall arrest system was not a conditioning cause of the fall, then the system will proceed to check if a safety belt was used as a part of the system (Cond 129). If it was, this will be considered a conditioning cause of the fall. Belts have been found to cause serious injuries to the fallen worker (see Chapter 4). Next, the system will check if the worker suffered excessive injuries as a result of the fall. If he or she did, the system will check if these injuries were due to the impact generated by a falling distance greater than 6 feet (Cond 130), impact with a lower structure (Cond 131), or impact with a lower side structure (Cond 132).

If the fall arrest system is a horizontal lifeline, the program will check the same variables as with the previous one. However, for the lifeline component, the program will check if it was designed and installed by a qualified professional with a factor of safety equal to 2 (Cond 135), or the horizontal lifeline showed excessive sagging (i.e., larger than 5 degrees) (Cond 138). The causes associated with the horizontal lifeline are portrayed in Figure 5.3 and Table 5.25.
Finally, if the fall arrest system is a self-retracting line, the program will check the same variables. However, if the falling distance is limited to less than two feet, its components only need to withstand a 3000 pounds (13.3 kN) tensile load. Otherwise, it still has to withstand 5000 pound (22.2 kN). The potential conditioning causes investigated for this component are included in Figure 5.3.

<table>
<thead>
<tr>
<th>Lanyard Conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using a knot</td>
<td>Cond 143</td>
</tr>
<tr>
<td>Tied to structural steel I or H beam</td>
<td>Cond 144</td>
</tr>
<tr>
<td>Passes around or over rough or sharp surfaces</td>
<td>Cond 145</td>
</tr>
</tbody>
</table>

Table 5.25: Decision table for lanyard strength reduction conditions (horizontal line)

If the safety device installed was a safety net system, the program will start by checking whether the fall occurred through a side unprotected by the net (e.g., next to the safety net). The safety net should extend a distance large enough to protect the entire edge and its side areas. If it does not, that problem will be considered a potential cause of a fall (Cond 179).

If the previous factor did not contribute to the fall, the system will check if any of the net’s components failed and prevented the net system from fulfilling its purpose. The net and its components should have a minimum breaking strength of 5000 pounds. If the net itself failed, it will be considered a conditioning cause of fall (Cond 182). Next, the system will try to establish if the failure was due to a lack of strength (Cond 180) or wear or fatigue (Cond 181). Furthermore, if the failing component was a net connection (Cond 210).
186), the system will investigate the connectors strength (Cond 183), connectors wear and fatigue (Cond 184), and their spacing (Cond 185). The spacing between connectors should be smaller than 6 inches (15 cm) in order to distribute the load impact to the support structure without failing. In addition, if the failing component is the support structure (Cond 190), the system will investigate its strength (Cond 188) and wear (Cond 189) conditions. Finally, if the user is not able to determine the specific net component that failed, but has indicated that the structure failed, that event will be represented by the Cond 187 cause.

If the net did not fail, the system will check if the net failed to catch the falling worker. If this was the case, both the vertical distance from the floor edge to the net and the horizontal outward extension of the net will be investigated (Table 5.26). If the falling distance is less than 5 feet (1.5 m), then the outward extension should be 8 feet (2.4 m). If the falling distance is between 5 and 10 feet (1.5 and 3 m), then the extension should be at least 10 feet (3 m). Finally if the falling distance is between 10 and 30 feet (3 and 9.1 m), the extension should be 13 feet (3.96 m). If the net extension is under those specified or if falling distance is greater than 30 feet (9.1 m), the outer fall momentum or wind effect may carry the worker past the net.

Next, the expert system will investigate if the impact of the fallen worker on the net caused it to hit a structure below it. If this was the case, that is the conditioning cause of fall (Cond 197). In this case, the system will also investigate if the falling distance to the net was excessive (larger than 30 feet); thus, causing it to deflect excessively (Cond 197) or the clearance distance underneath the net was not adequate (Cond 194).
Finally, if the net caught the worker but the worker was injured, the system will check if the injury was due to problems related to excessive falling distance (Cond 198), the worker hitting a piece of scrap or material on the net (Cond 199), or a body member of the worker going through a mesh hole. If the latter problem is true, the conditions of the net mesh will be examined (Table 5.27).

<table>
<thead>
<tr>
<th>Net Mesh Conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>The net mesh area is smaller than 36 square inches</td>
<td>Cond 200</td>
</tr>
<tr>
<td>The net crossings are not tied up</td>
<td>Cond 201</td>
</tr>
<tr>
<td>The net was worn out or damaged</td>
<td>Cond 202</td>
</tr>
</tbody>
</table>

Table 5.27: Decision table for net mesh conditions

Finally, if none of the other potential fall protection devices were used to protect the floor edge, the system will check if a Control Access Zone (CAZ) was used. If it was not, the system will conclude the consultation by displaying the final conclusion and

<table>
<thead>
<tr>
<th>Vertical distance from surface to net (ft)</th>
<th>Safety net outward extension (ft)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5</td>
<td>&gt; 8</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 5</td>
<td>&lt;= 8</td>
<td>Cond 191</td>
</tr>
<tr>
<td>5 - 10</td>
<td>&gt; 10</td>
<td>o.k.</td>
</tr>
<tr>
<td>5 - 10</td>
<td>&lt;= 10</td>
<td>Cond 191</td>
</tr>
<tr>
<td>10 - 30</td>
<td>&gt; 30</td>
<td>o.k.</td>
</tr>
<tr>
<td>10 - 30</td>
<td>&lt;= 30</td>
<td>Cond 191</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>------</td>
<td>Cond 192</td>
</tr>
</tbody>
</table>

Table 5.26: Decision table for safety net distances
recommendations. If the CAZ was used, the system will check if the special conditions under which this device could be used were present in the site (Table 5.28). If they were, the system will investigate whether the fallen worker was authorized to work on the CAZ. If he or she was not, the possible reasons for its presence inside it will be investigated (i.e., CAZ collapse, worker tripped on the line, the worker walked under the line, or the worker walked through an unprotected area—the CAZ was not completely enclosed). Finally, the system will determine whether a safety monitoring system was used (Cond 210) and was operated properly (Cond 211 to Cond 214).

<table>
<thead>
<tr>
<th>CAZ conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading edge work</td>
<td>o.k.</td>
</tr>
<tr>
<td>Edge overhand bricklaying work</td>
<td>o.k.</td>
</tr>
<tr>
<td>Edge precast concrete erection work</td>
<td>o.k.</td>
</tr>
<tr>
<td>Use of conventional fall protection devices was unfeasible</td>
<td>o.k.</td>
</tr>
<tr>
<td>Use of conventional fall protection devices was more hazardous</td>
<td>o.k.</td>
</tr>
<tr>
<td>None of the above</td>
<td>Cond 203</td>
</tr>
</tbody>
</table>

Table 5.28 Decision table for CAZ conditions
Figure 5.3: Decision Structure for Worker Fall from Floor Edge Investigation

To be continued
Figure 5.3 (Continued)

Floor Exposed to Weather?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Weather Gust Conditions?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Gust Impact?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

FEBas 21  
1

Weather Hail Conditions?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Hail Impact?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

FEBas 22  
1

Weather Rain, Snow, Hail Conditions?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Worker Slip with Water, Ice on Floor?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Barricades or Warning Signs Used?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

FEBas 23  
1

FEBas 24  
1

Worker Extremely Hot Conditions?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Worker Collapse due to Dehydration?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

FEBas 25  
1

Small materials (e.g., gravel) on Floor?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Worker Slip?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

Barricades or Warning Signs Used?  
\[ \begin{array}{c}
\text{Y} \\
\text{N}
\end{array} \]

FEBas 26  
1

FEBas 27  
1

To be continued
Figure 5.3 (Continued)
Figure 5.3 (Continued)

- Tools or Materials on the Floor? (Y/N)
  - Worker Trip? (Y/N)
    - Specific Areas on Floor to Store Tools and Place Materials? (Y/N)
      - FEBas 38
      - FEBas 39
  - Chronic Health Problem? (Y/N)
    - Worker Collapse due to Chronic Problem? (Y/N)
  - Acute Health Problem? (Y/N)
    - Worker Collapse due to Acute Problem? (Y/N)
    - FEBas 41
  - History of Alcohol Related Problems? (Y/N)
    - Worker Drinking before or during Work? (Y/N)
      - FEBas 42
  - History of Drug Abuse Problems? (Y/N)
    - Worker using Drugs before or during Work? (Y/N)
      - FEBas 43

To be continued
Figure 5.3 (Continued)

Worker Taking Prescription or Over the Counter Medicine?

Worker Collapse due to Side Effects (e.g., Drowsy)?

Worker Seem to notice Floor Edge?

If Weather exposed and Rain, Snow, Hail, Fog, Poor Visibility?

If Weather Exposed and Rain, Snow, Hail, Extreme Heat, or Extreme Cold, Worker Distracted?

Worker Distracted by Occurrence on Surroundings?

Worker Distracted by Personal Problems (Stress)?

Worker Reckless Behavior Tendency?

Worker Acting Recklessly at the Time of the Accident?

Worker Trained or Experienced

To be continued
Figure 5.3 (Continued)

Worker did not seem to notice the hazard?

Floor Exposed to Weather Conditions?

If Rain, Snow, Hail, or Fog. Poor Visibility?

If Rain, Snow, Hail, Extreme Heat, or Extreme Cold. Worker Distracted?

Worker Distracted by Occurrence on Surroundings?

Worker Distracted by Personal Problems (Stress)?

Worker Trained or Experienced?

FEBas 55

To be continued
Figure 5.3 (Continued)
Figure 5.3 (Continued)

Rail/Post Connection Failure?  
Y  
Inadequate Connection?  
N  Cond 34  
Y  Cond 33  
N  
Post/Floor Connection Failure?  
Y  Inadequate Connection?  
N  Cond 36  
Y  Cond 35  
Worker Topple Over Guardrail (TR)?  
Y  Guardrail Top Rail Missing?  
N  Cond 37  
Y  Guardrail Top Rail Low Elevation?  
N  Cond 38  
Y  Guardrail Post Spacing larger than 8 feet?  
N  Cond 39  
Y  

to be continued
Figure 5.3 (Continued)

Worker Fall Through Area Below Top Rail?  
\[ \text{N, DK} \]

Guardrail Mid Rail Missing?  
\[ \text{Y} \rightarrow \text{Cond 40} \]

Guardrail ToeBoard Missing?  
\[ \text{N} \rightarrow \text{Prob 41} \]

Guardrail Rails Elevation?  
\[ \text{Y} \rightarrow \text{Cond 45} \]

Guardrail Post Spacing larger than 8 feet?  
\[ \text{N} \rightarrow \text{Prob 14} \]

If topple over TR and fall below TR are DK?  
\[ \text{Y} \rightarrow \text{Guardrail Component Missing?} \]

Guardrail Component Missing?  
\[ \text{Table 5.11} \]

Guardrail Rails Elevations?  
\[ \text{Table 5.10} \]

C. Cause?  
\[ \text{Y} \rightarrow \text{Cond 50} \]

Fall from Loading Zone?  
\[ \text{N} \rightarrow \text{Worker Doing Job in Zone?} \]

Method to Control Access to Zone?  
\[ \text{N} \rightarrow \text{Other Protection. Fall Arrest?} \]

Other Protection. Safety Net?  
\[ \text{N} \rightarrow \text{Cond 53} \]

Final Conclusion

To be continued
Figure 5.3 (Continued)

- Catch Platform Installed?
- Fall Through Opening between Edge and Scaffold?
- Scaffold Component Collapse?
- CP Floor Enabling Problem?
- CP Floor Triggering Problem?
- CP Floor Support Problem?
- Fall Through Scaffold Side Not Protected by Guardrail?

To be continued
Figure 5.3 (Continued)

CP Guardrail System Installed?

Guardrail Top Rail Failure?
- Wood? (Y) Table 5.12
- Pipe? (N)
  - Str. Steel? (Y) Table 5.14
  - Other? (N) Cond 64
- TR Wear? (Y) Cond 65
  - Post Space? (Y) Cond 66
  - Post Wear? (Y) Cond 74
  - Post Space? (N)
  - Cond 67
- Cond 60
- Cond 60
- Cond 60

Guardrail Mid Rail Failure?
- Wood? (Y) Table 5.15
- Pipe? (N)
  - Str. Steel? (Y) Table 5.17
  - Other? (N) Cond 71
- TR Wear? (Y) Cond 72
  - Post Space? (Y) Cond 73
  - Post Space? (N)
  - Cond 74
  
Guardrail Posts Failure?
- Wood? (Y) Table 5.18
- Pipe? (N)
  - Str. Steel? (Y) Table 5.20
  - Other? (N) Cond 78
- Post Wear? (Y) Cond 79

To be continued
Figure 5.3 (Continued)
Figure 5.3 (Continued)

Worker Fall Through Area Below TopRail?

Guardrail Mid Rail Missing?

Guardrail ToeBoard Missing?

Guardrail Mid Rail Low Elevation?

Guardrail Post Spacing larger than 8 feet?

If topple over TR and fall below TR are DK?

Guardrail Component Missing?

Guardrail Rails Elevations?

Guardrail Posts Spacing > 8 ft.

C. Cause?

To be continued
Figure 5.3 (Continued)

1. Fall Arrest System Installed?
   - Yes: Worker Connected to System?
   - No: Failing Component, Anchorage?
   - Yes: Anchorage Adequate Strength?
   - No: Anchorage Wear or Fatigue?
   - Yes: Lifeline Conditions?
   - No: Table 5.23

2. Vertical lifeline and Lanyard?
   - Yes: Failing Component, Lifeline?
   - No: More than One Lanyard Attached?
   - Yes: Lifeline Adequate Strength?
   - No: Lifeline Wear or Fatigue?
   - Yes: C. Cause?
   - No: Cond 112

To be continued
Figure 5.3 (Continued)
To be continued
Figure 5.3 (Continued)

Horizontal lifeline and Lanyard?

- If Yes, go to Failing Component, Anchorage?
  - If Yes, go to Anchorage Adequate Strength?
    - If Yes, go to Cond 133
    - If No, go to Anchorage Wear or Fatigue?
      - If Yes, go to Cond 134
      - If No, go to Cond 135

- If No, go to Failing Component, Lifeline?
  - If Yes, go to Designed and Installed by Qualified Person?
    - If Yes, go to Cond 136
    - If No, go to Lanyard A(dequate Strength?
      - If Yes, go to Cond 141
      - If No, go to Lanyard Wear or Fatigue?
        - If Yes, go to Cond 142
        - If No, go to Lanyard Conditions?
          - If Yes, go to Table 5.25
          - If No, go to Lifeline Sagging?
            - If Yes, go to Cond 139
            - If No, go to Cond 140

To be continued
Figure 5.3 (Continued)

- **Failing Component. Snaphook?**
  - Y: Snaphook Adequate Strength?
    - N: Snaphook Wear or Fatigue?
      - Y: Cond 147
      - N: Cond 148
    - Y: Cond 146
  - N: To be continued

- **Failing Component. Deering or Connector?**
  - Y: D or C Adequate Strength?
    - N: Cond 149
    - Y: D or C Wear or Fatigue?
      - N: Cond 150
      - Y: Cond 151
  - N: To be continued

- **Failing Component. Harness?**
  - Y: Harness Adequate Strength?
    - N: Cond 152
    - Y: Harness Wear or Fatigue?
      - N: Cond 153
      - Y: Cond 154
  - N: To be continued
Figure 5.3 (Continued)
Figure 5.3 (Continued)

Failing Component. Lifeline?  
N  
Y  
More than One Worker Attached?  
N  
Y  
Lifeline Adequate Strength?  
N  
Y  
Lifeline Wear or Fatigue?  
N  
Y  
Cond 162  
Cond 163  
Cond 164  
Cond 165

Failing Component. Snaphook?  
N  
Y  
Snaphook Adequate Strength?  
N  
Y  
Snaphook Wear or Fatigue?  
N  
Y  
Cond 166  
Cond 167  
Cond 168

Failing Component. Deering or Connector?  
N  
Y  
D or C Adequate Strength?  
N  
Y  
D or C Wear or Fatigue?  
N  
Y  
Cond 169  
Cond 170  
Cond 171

To be continued
Figure 5.3 (Continued)
Figure 5.3 (Continued)

4. Safety Net System Installed?  
   - N: 5
   - Y: Worker Fell Through Unprotected Side?  
     - N: Cond 179  
       - Final Conclusion
     - Y: Net Failed Under Worker Impact?  
       - N: Failing Component. Connection?  
         - N: Cond 183  
           - Final Conclusion
         - Y: Connection Adequate Strength?  
           - Y: Final Conclusion
           - N: Net Wear or Fatigue?  
             - Y: Final Conclusion
             - N: Cond 184  
               - Final Conclusion
         - N: Net Adequate Strength?  
           - Y: Final Conclusion
           - N: Cond 182  
             - Final Conclusion
       - Y: Failing Component. Net?  
         - N: Cond 180  
           - Final Conclusion
         - Y: Final Conclusion

To be continued
Figure 5.3 (Continued)

- Failing Component: Net Support Structure?  
  - Y: Final Conclusion  
  - N: Cond 187 → Final Conclusion

- Support Structure Adequate Strength?  
  - Y: Final Conclusion

- Support Structure Wear or Fatigue?  
  - Y: Cond 189 → Final Conclusion

- N: Cond 190 → Final Conclusion

- Vertical Dist. to Net?  
  - Net Support Structure?  
    - Y: Final Conclusion
    - N: Cond 187
  - Table 5.26

- Clearance Distance Under Net Adequate?  
  - Y: Cond 194
  - N: Cond 193 → Final Conclusion

- Vertical Distance to Net Adequate?  
  - Y: Cond 197
  - N: Cond 195 → Final Conclusion

- Worker Injured Due to Fall?  
  - Y: Cond 198
  - N: Cond 199 → Final Conclusion

- Adequate Vertical Dist. to Net?  
  - Y: Cond 198
  - N: Final Conclusion

- Safety Net Mesh Conditions?  
  - Y: Table 5.27

To be continued
Figure 5.3 (Continued)

1. Control Access Zone Installed?
   - Y: Control Access Zone Conditions?
     - Y: Table 5.28
     - N: Final Conclusion
   - N: Final Conclusion

2. Worker Authorized to be in CAZ?
   - Y: CAZ Collapse?
     - Y: Condition 204
     - N: Final Conclusion
   - N: CAZ Height is too low?
     - Y: Condition 207
     - N: Final Conclusion

3. CAZ Adequate Strength?
   - Y: Condition 205
   - N: Condition 206

To be continued
Figure 5.3 (Continued)

- **CAZ Height is too High?**
  - Y: Worker Walked Under the Line?
  - N: Cond 208
- **CAZ Unprotected Area?**
  - Y: Cond 209
  - N: Final Conclusion
- **Safety Monitoring?**
  - Y: Worker Failed to Comply with Warning?
  - N: Final Conclusion
- **Monitor Failed to Warn Worker?**
  - Y: Monitor had Other Functions?
  - N: Cond 213
  - N: Cond 214
  - N: Final Conclusion
- **Monitor within Range?**
  - Y: Final Conclusion
  - N: Cond 211
  - N: Cond 212
  - N: Final Conclusion

Cond 210

Final Conclusion
6.1 Introduction

This chapter discusses the expert system module developed for evaluating fall site safety (branch highlighted on Figure 6.1). The research methods used for the development of this expert system include the following: knowledge acquisition, knowledge representation, expert system development, and system testing and validation. The knowledge used to develop the knowledge base for this program is based on the knowledge about fall safety devices obtained during the fault tree structures development (see Chapter 4). Thus, the knowledge acquisition process is similar to the one discussed on Chapter 5. The focus of this chapter is on discussing the knowledge structure develop to achieve the evaluation task. The system implementation and evaluation tasks are discussed on Chapters 8 and 9 of this report.

The evaluation module of the SAFETY FIRST program consists of four different knowledge bases. A knowledge base to evaluate the fall safety of each of the following elevated components: floors (including floor edges, floor openings, and wall openings), roofs (including flat and pitched roofs, and roof edges and roof skylights), steel beams, and form scaffoldings. It is expected that this module of the SAFETY FIRST program will
be used by site and project managers to evaluate the fall protection safety implemented in the site, detect any ‘weak links’ on these safety measures (if any), and implement appropriate measures to eliminate them.

![Program Structure (Fall Safety Evaluation Module)](image)

Figure 6.1: Program Structure (Fall Safety Evaluation Module)

6.2 Decision Structures for a Floor Edge

This section discusses one of the decision structures (i.e., floor edge) developed to represent the knowledge needed to evaluate the soundness of the fall safety practices implemented in the site at the time of the evaluation. As the structure discussed in Chapter 5, the structure is a combination of decision trees and decision tables which have been found effective to represent both causality knowledge and evidentiary knowledge needed by the system to reach a conclusion. The other decision structures developed for this module of the program are included on Appendix D of this report.
To begin the consultation, the system will proceed to ask whether or not there is any fall protection device protecting the floor edge. If the answer to this question is “no,” then such a problem is considered a major problem which may lead to a fall (Prob 1) and the system will finish the consultation. On the other hand, if the answer to the question is “yes,” then the system will ask the user to select from a list of devices used on the floor edge and then will proceed to analyze their adequacy.

The following fall protection devices have been deemed adequate to protect the worker around a floor edge: a standard guardrail, a catch platform, a fall arrest system, a safety net system, and a Controlled Access Zone (CAZ). These devices are analyzed in the order listed, which is also the order in which they are preferred or used in construction sites. The guardrail system is the most desirable because it doesn’t require the active participation of the worker for its success in preventing falls and its ease of erection. In contrast to belt and body harness systems, which require worker involvement and depend on several components working together for its success. Therefore, once the user has indicated that a fall protection/prevention device was being used in the site, the system will check if that system is a guardrail; if it is, then the system it will proceed to evaluate its adequacy. If it is not, then it will check whether the device installed is a catch platform. If the answer is “yes,” the system will evaluate its adequacy, otherwise it will go on to the fall arrest system and so on until the CAZ is reached. In case none of the listed fall protection devices is the one provided on the site, the system also provides the “other” option which allows the user to specify the device and analyze its adequacy according to OSHA standards.
There are some limitations in the combination of devices that may be used at the same time. The guardrail and catch platform systems cannot be selected at the same time given that they perform the same function (i.e., the catch platform's guardrail acts as a fall protection system). Similarly, a catch platform and a safety net cannot be erected to protect the same floor edge due to space limitations. The controlled access zone can only be used when none of the other devices can be used and therefore, if this device is used, then none of the others is chosen. Finally, if the other device option is chosen, the system assumes that none of the other options provided apply. These constraints are reflected in the decision structure developed.

If the guardrail system is installed, then the system will proceed to analyze it. The first question asked of the user is whether any of the guardrail's regular components is missing and to identify any problematic condition according to the Table 6.1. If the user indicates that both the top and middle rails are missing in the guardrail system, the system will indicate that without those components there is no guardrail and the user should go back and indicate so. The lack of a top rail is a significant problem because without it the guardrail is not high enough to be able to prevent the worker from falling (Prob 2). The lack of an intermediate rail is significant because the space between the top rail and the ground is too large and the worker may fall through it (Prob 3). The lack of posts is significant because the rails at the mid point may not be high enough to prevent the worker fall (due to sag at mid-point). In addition, depending on the material, the lack of support every 8 feet (2.4 m) may reduce the strength resistance of the rail (Prob 4). Finally, the lack of toeboard is significant if the basic cause of a fall was a worker slip. In
such a case, the worker may slide under the middle rail and fall due to the lack of this barrier (Prob 5).

<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Posts</th>
<th>Toe Board</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>Prob 4, Prob 5</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>Prob 3, Prob 4, Prob 5</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 2, Prob 4</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 2, Prob 5</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 3, Prob 4</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 3, Prob 5</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 4, Prob 5</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 2</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 3</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 4</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 5</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.1: Decision table for guardrail components missing

Next, the system will ask the user about the top and middle rail elevations, which should be 42 +/- 3 inches (1100 +/- 80 mm) and 21 +/- 1.5 inches (550 +/- 40 mm) in order to be able to stop a worker from falling. In this case if the top rail is too low (less than 39 inches or 1.02 m high) the worker may trip over the rail and fall (Prob 7). Furthermore, if the top rail is too high (above 45 inches or 1.18 m high), there are two possible problems: the space between the top and mid rail is too large (Prob 8) or the space between the mid-rail and toeboard/ground is too large (Prob 9). In either case the
worker may fall through the opening. The final case is if the top rail elevation is adequate but the mid-rail is too low (Prob 8) or too high (Prob 9). All of these combinations are portrayed in Table 6.2. The system's next question regards the posts spacing (Table 6.3). If the spacing is less than 8.5 feet (2.6 m), it is adequate. Otherwise, the spacing is too large and sagging and strength problems may occur (Prob 10).

<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Prob 8</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Prob 9</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>Prob 8</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Prob 9</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Prob 8</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>Prob 7</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Prob 7</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Prob 7</td>
</tr>
</tbody>
</table>

Table 6.2: Decision table for guardrail elevations

<table>
<thead>
<tr>
<th>Post Spacing</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8 - 0.5 ft (2.4 - 2 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 8 + 0.5 ft (2.4 + 2 m)</td>
<td>Prob 10</td>
</tr>
</tbody>
</table>

Table 6.3: Decision table for post spacing

Subsequently, the system starts to evaluate the guardrail strength. To do this, the system uses the type of material used and the cross-section or diameter of the top and middle rails and the posts. Therefore, if the material used to build the guardrail is wood
the cross-sectional measures of the top rail should be at least 2 x 4 inches (50 x 100 mm) and the cross section of the mid-rail should be at least 1 x 6 inches (25 x 150 mm). If the size of any of these component sections is smaller than the one specified, the undersized component of the system is not strong enough to support the worker impact (Prob 11 and Prob 13). All of the possible decisions are depicted in Decision Tables III-4.4 and III-4.5.

If the material used to build the guardrail is pipe (Table 6.6), then the diameter of the rail cross section should be at least 1.5 inches (40 mm) for all the components (top and middle rails, and posts). If this diameter is less than that, then the system's strength will be inadequate (Prob 13).

If L-shaped structural steel is used to build the guardrail, then the cross section should be at least 2 x 2 x 0.375 inches (50x50x11 mm) in order to be strong enough to support a worker impact load and prevent him from falling. This lack of strength, if present, is a problem which may lead to a fall (Prob 14) and may occur in the different forms depicted in Table 6.7.

If the material used for the rails is wire rope, then we know that this material complies with the strength standards set by OSHA and so the system will go on to evaluate the posts materials. Furthermore, if the materials used for the rails are made up of steel or plastic bands, it is already known that these materials are not adequate to for fall protection; therefore, the system will conclude that their use is a problem (Prob 16). If none of the previously named materials was the one used for the guardrail, the user is allowed to indicate the material used and determine if it complies with strength requirements. The top rail should be able to withstand with a minimum deflection a load of
200 pounds (890 N), while the intermediate rail should be able to stand a load of 150 pounds (666 N) without breaking. Based on these requirements the user can judge the guardrail and reach a conclusion regarding its adequacy (Table 6.8).

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 11</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>Prob 11</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 11</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>Prob 11</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 11</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.4: Decision table for wood top rail cross section

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch (25 mm)</td>
<td>6 inches (150 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>1 inch (25 mm)</td>
<td>&lt; 6 inches (&lt; 150 mm)</td>
<td>Prob 12</td>
</tr>
<tr>
<td>1 inch (25 mm)</td>
<td>&gt; 6 inches (&gt; 150 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1 inch (&lt; 25 mm)</td>
<td>6 inches (150 mm)</td>
<td>Prob 12</td>
</tr>
<tr>
<td>&lt; 1 inch (&lt; 25 mm)</td>
<td>&lt; 6 inches (&lt; 150 mm)</td>
<td>Prob 12</td>
</tr>
<tr>
<td>&lt; 1 inch (&lt; 25 mm)</td>
<td>&gt; 6 inches (&gt; 150 mm)</td>
<td>Prob 12</td>
</tr>
<tr>
<td>&gt; 1 inch (&gt; 25 mm)</td>
<td>6 inches (150 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 1 inch (&gt; 25 mm)</td>
<td>&lt; 6 inches (&lt; 150 mm)</td>
<td>Prob 12</td>
</tr>
<tr>
<td>&gt; 1 inch (&gt; 25 mm)</td>
<td>&gt; 6 inches (&gt; 150 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.5: Decision table for wood mid-rail cross section
<table>
<thead>
<tr>
<th>Diameter (In)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt; 40 mm)</td>
<td>Prob 13</td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.6: Decision table for pipe rail diameter

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 14</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.7: Decision table for L-shaped steel rails
Table 6.8: Decision table for other material rails

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 17</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>Prob 17</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 17</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>Prob 17</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 17</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.9: Decision table for wood posts cross section

As for the guardrail post materials, their strength is evaluated in the same way. If wood is being used, then the post’s cross-section should be at least two by four inches (50x100 mm) (Table 6.9). If the cross-section is smaller than that, then the posts are deemed inadequate (Prob 17). For posts made of pipe material (Table 6.10), as long as the pipe diameter is more than 1.5 inches (40 mm) the posts are adequate; otherwise, it will fail strength requirements (Prob 18). Further, if the posts material is L-shaped structural steel (Table 6.11), the posts will fail to be adequate if their cross sectional measures are
smaller than 2x2x0.375 inches (50x50x11 mm) (Prob 19). Finally, if any other material is used (Table 6.12), the posts should be able to withstand a 200 pound (890 N) load. Failure to do so, will be deemed a strength problem (Prob 20).

### Table 6.11: Decision table for L-shaped steel posts

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>Prob 19</td>
</tr>
</tbody>
</table>

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Finally, the system will evaluate whether the guardrail components are secured well to each other and to the working surface (Tables 6.13 and 6.14) and whether these components were in good condition or showed any signs of rust, corrosion, wear, etc. (Table 6.15).

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt; 40 mm)</td>
<td>Prob 18</td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.10: Decision table for pipe posts diameter

<table>
<thead>
<tr>
<th>Posts Material up to Strength Standards</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 20</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.12: Decision table for Other material posts

<table>
<thead>
<tr>
<th>Rails well secured to posts</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 21</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.13: Decision table for rails secured to posts
Table 6.14: Decision table for posts secured to surface

<table>
<thead>
<tr>
<th>Posts well secured to surface</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 22</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.15: Decision table for guardrail components wear

<table>
<thead>
<tr>
<th>Guardrail components show signs of wear or fatigue</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 23</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

After this, the guardrail evaluation is completed and the system will proceed to evaluate either another safety device adequacy (if more than one fall protection device was being used) or the basic causes.

If the fall protection device installed is a catch platform, the system will ask the user to indicate the horizontal distance between the catch platform inner edge and the floor edge. If this distance is more than one ft (304.7 mm), then the distance will be considered too large, given that a worker may fall through it (Prob 24).

Next, the system will inquire about the position of the catch platform floor with respect to the working surface floor (Table 6.17). If the CP’s floor is at a level above the one of the work surface, the worker may trip on it (Prob 25). If it is below it, then a
distracted worker may also trip due to the sudden level change (Prob 26). If both floors are at the same level, then the catch platform erection is adequate in that aspect.

<table>
<thead>
<tr>
<th>Horizontal distance between CP and floor edge</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 ft (304 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>Larger than or equal to 1 (304 mm)</td>
<td>Prob 24</td>
</tr>
</tbody>
</table>

Table 6.16: Decision table for distance to edge

<table>
<thead>
<tr>
<th>CP floor location with respect to the working area floor</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above</td>
<td>Prob 25</td>
</tr>
<tr>
<td>Below</td>
<td>Prob 26</td>
</tr>
<tr>
<td>Same level</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.17: Decision table for catch platform location

Next, the system will ask the user if the platform was installed according to OSHA standards and the manufacturers specifications. If it is not, the structure may fail to perform its functions (Prob 27). The strength of the structure is also checked. The platform should be able to withstand four times the maximum load that will be applied to it. If the system fails to do so, it will be deemed to have a strength problem (Prob 28). Related to the platform’s strength is the strength of its floor, if the floor is not made up of scaffold grade wood or metal sheet, it may not be strong enough and therefore likely to
fail (Prob 29). Finally, if the platform components showed some signs of wear or fatigue, then it may fail under unexpected loads (Prob 30).

<table>
<thead>
<tr>
<th>CP installed according to manufacturers specifications</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 27</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.18: Decision table for catch platform installation

<table>
<thead>
<tr>
<th>Catch platform strength adequate</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 28</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.19: Decision table for catch platform strength

<table>
<thead>
<tr>
<th>CP’s floor made of scaffold grade wood or metal sheet</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 29</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.20: Decision table for catch platform floor materials

<table>
<thead>
<tr>
<th>CP components show signs of wear or fatigue</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Prob 30</td>
</tr>
<tr>
<td>No</td>
<td>o.k.</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.21: Decision table for Catch platform components wear
Given that the catch platform has to perform the same functions as the guardrail system, the next step is to evaluate the catch platform's guardrail. The lack of a guardrail system in the platform may lead to a fall accident (Prob 31). If a guardrail is installed to protect the catch platform, it will be evaluated for the same conditions, the guardrail system for a working surface edge was evaluated. Therefore, the individual decision making factors will not be discussed again here. However, they are portrayed in Tables 6.22 to 6.36.

<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Posts</th>
<th>Toe Board</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>Prob 32, Prob 33</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
<td>Prob 33, Prob 34,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Prob 35</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>no guardrail</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 32, Prob 34</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 32, Prob 35</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 33, Prob 34</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 33, Prob 35</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 34, Prob 35</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 32</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 33</td>
</tr>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>Prob 34</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Prob 35</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.22: Decision table for CP's guardrail components missing
<table>
<thead>
<tr>
<th>Top Rail</th>
<th>Mid-Rail</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Prob 37</td>
</tr>
<tr>
<td>42 +/- 3 inches (1100 +/- 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Prob 38</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>Prob 37</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Prob 38</td>
</tr>
<tr>
<td>&gt; 42 + 3 inches (&gt; 1100 + 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Prob 37</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>21 +/- 3 inches (550 +/- 40 mm)</td>
<td>Prob 36</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>&gt; 21 + 3 inches (&gt; 550 + 40 mm)</td>
<td>Prob 38</td>
</tr>
<tr>
<td>&lt; 42 - 3 inches (&lt; 1100 - 80 mm)</td>
<td>&lt; 21 - 3 inches (&lt; 550 - 40 mm)</td>
<td>Prob 36</td>
</tr>
</tbody>
</table>

Table 6.23: Decision table for CP’s guardrail rail elevations

<table>
<thead>
<tr>
<th>Post Spacing</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8 - 0.5 ft (2.4 -.2 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 8 + 0.5 ft (2.4 +.2 m)</td>
<td>Prob 9</td>
</tr>
</tbody>
</table>

Table 6.24: Decision table for CP’s guardrail post spacing

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 40</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>Prob 40</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 40</td>
</tr>
<tr>
<td>&lt; 2 inches (&lt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>Prob 40</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>4 inches (100 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&lt; 4 inches (&lt; 100 mm)</td>
<td>Prob 40</td>
</tr>
<tr>
<td>&gt; 2 inches (&gt; 50 mm)</td>
<td>&gt; 4 inches (&gt; 100 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.25: Decision table for CP’s guardrail wood top rail cross section
<table>
<thead>
<tr>
<th>Width (in)</th>
<th>Height (in)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 inch (25 mm)</td>
<td>6 inches (150 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1 inch (&lt; 25 mm)</td>
<td>6 inches (150 mm)</td>
<td>Prob 41</td>
</tr>
<tr>
<td>&gt; 1 inch (&gt; 25 mm)</td>
<td>6 inches (150 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.26: Decision table for CP’s guardrail wood mid-rail cross section

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches (40 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 1.5 inches (&lt; 40 mm)</td>
<td>Prob 42</td>
</tr>
<tr>
<td>&gt; 1.5 inches (&gt; 40 mm)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.27: Decision table for CP’s guardrail pipe rail diameter
<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Depth</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
<td>&gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
</tr>
<tr>
<td>2 inches (50 mm) &lt; 2 inches (50 mm)</td>
<td>0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
</tr>
<tr>
<td>2 inches (50 mm) &lt; 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 inches (50 mm) &lt; 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 inches (50 mm) &gt; 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 inches (50 mm) &gt; 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 inches (50 mm) &gt; 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) &lt; 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) &lt; 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) &lt; 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) &gt; 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) &gt; 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm) &gt; 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) &lt; 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) &lt; 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) &lt; 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) &gt; 2 inches (50 mm) 0.375 inches (11 mm)</td>
<td>o.k.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) &gt; 2 inches (50 mm) &lt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm) &gt; 2 inches (50 mm) &gt; 0.375 inches (11 mm)</td>
<td>Prob 43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6.28: Decision table for CP's guardrail L-shaped steel rails

<table>
<thead>
<tr>
<th>Rail Material up to Strength Standards</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 44</td>
</tr>
<tr>
<td>Don't know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.29: Decision table for CP's guardrail other material rails
### Table 6.30: Decision table for CP’s guardrail wood posts cross section

<table>
<thead>
<tr>
<th>Width</th>
<th>Height</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 inches</td>
<td>4 inches</td>
<td>o.k.</td>
</tr>
<tr>
<td>(50 mm)</td>
<td>(100 mm)</td>
<td></td>
</tr>
<tr>
<td>2 inches</td>
<td>&lt; 4 inches</td>
<td>Prob 45</td>
</tr>
<tr>
<td>(50 mm)</td>
<td>(&lt; 100 mm)</td>
<td></td>
</tr>
<tr>
<td>2 inches</td>
<td>&gt; 4 inches</td>
<td>o.k.</td>
</tr>
<tr>
<td>(50 mm)</td>
<td>(&gt; 100 mm)</td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches</td>
<td>4 inches</td>
<td>Prob 45</td>
</tr>
<tr>
<td>(&lt; 50 mm)</td>
<td>(100 mm)</td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches</td>
<td>&lt; 4 inches</td>
<td>Prob 45</td>
</tr>
<tr>
<td>(&lt; 50 mm)</td>
<td>(&lt; 100 mm)</td>
<td></td>
</tr>
<tr>
<td>&lt; 2 inches</td>
<td>&gt; 4 inches</td>
<td>Prob 45</td>
</tr>
<tr>
<td>(&lt; 50 mm)</td>
<td>(&gt; 100 mm)</td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches</td>
<td>4 inches</td>
<td>o.k.</td>
</tr>
<tr>
<td>(&gt; 50 mm)</td>
<td>(100 mm)</td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches</td>
<td>&lt; 4 inches</td>
<td>Prob 45</td>
</tr>
<tr>
<td>(&gt; 50 mm)</td>
<td>(&lt; 100 mm)</td>
<td></td>
</tr>
<tr>
<td>&gt; 2 inches</td>
<td>&gt; 4 inches</td>
<td>o.k.</td>
</tr>
<tr>
<td>(&gt; 50 mm)</td>
<td>(&gt; 100 mm)</td>
<td></td>
</tr>
</tbody>
</table>

### Table 6.31: Decision table for CP’s guardrail pipe posts diameter

<table>
<thead>
<tr>
<th>Diameter (In)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches</td>
<td>o.k.</td>
</tr>
<tr>
<td>(40 mm)</td>
<td></td>
</tr>
<tr>
<td>&lt; 1.5 inches</td>
<td>Prob 46</td>
</tr>
<tr>
<td>(&lt; 40 mm)</td>
<td></td>
</tr>
<tr>
<td>&gt; 1.5 inches</td>
<td>o.k.</td>
</tr>
<tr>
<td>(&gt; 40 mm)</td>
<td></td>
</tr>
<tr>
<td>Width</td>
<td>Height</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&lt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&lt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
<tr>
<td>&gt; 2 inches (50 mm)</td>
<td>&gt; 2 inches (50 mm)</td>
</tr>
</tbody>
</table>

Table 6.32: Decision table for CP’s guardrail L-shaped steel posts

<table>
<thead>
<tr>
<th>Posts Material up to Strength Standards</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 48</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.33: Decision table for CP’s guardrail other material posts
<table>
<thead>
<tr>
<th>Rails well secured to posts</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 49</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.34: Decision table for CP’s guardrail rails secured to posts

<table>
<thead>
<tr>
<th>Posts well secured to platform</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 50</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.35: Decision table for CP’s guardrail posts secured to platform

<table>
<thead>
<tr>
<th>Guardrail components show signs of wear or fatigue</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Prob 51</td>
</tr>
<tr>
<td>No</td>
<td>o.k.</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.36: Decision table for CP’s guardrail components wear

Fall arrest systems can be grouped into the following: vertical lifeline and lanyard, horizontal lifeline, and self-retracting lines. The system will analyze the one that is being used in the site. For a vertical lifeline and lanyard, the first factor considered is the falling distance allowed by the system and the distance to the ground or the closest surface (Table
If the falling distance is above 6 feet (1.8 m) the risk of injury is too great (Prob 52). In addition, if the falling distance allowed by the system is larger than the distance to the nearest surface, then the fall arrest usefulness will be defeated given that the worker will impact this surface (Prob 53). Next, the system will check the system’s anchorage point strength (Table 6.38). The anchor has to be able to withstand a load of 5000 pounds (22.2 kN) per employee attached (Prob 54) and no guardrails or hoists devices should be used as anchors (Prob 55). Furthermore, the system lifelines and lanyard should be able to withstand a load of 5000 pounds (22.2 kN) (Table 6.39) and the deerings and snaphooks a load of 3600 pounds (16 kN) (Table 6.40). If locking snaphooks are not being used, then there is a risk that the snaphook will accidentally open, especially if certain given conditions occur in the system (Table 6.41). Furthermore, if the fall arrest force is larger than 1800 pounds (8 kN) and the deceleration distance is larger than 3.5 feet (1.07 m), the worker may be injured (Prob 63). Finally, the system will check for wear and fatigue (Table 6.43).

If the fall arrest system is a horizontal lifeline the system will still check the distance to the ground and falling distance (Table 6.37), whether the horizontal line was designed and installed under engineering supervision (Table 6.44), the line and lanyard strength (Table 6.39), the use of locking snaphooks (Table 6.45) the fall arrest force and deceleration distance (Table 6.42), and the wear and fatigue of the system’s components (Table 6.43).

If the fall arrest system is a self-retracting line, the system will still check the free falling distance allowed by the system (Table 6.46), the line strength (Table 6.39), the
deerings and snaphooks strength, the locking snaphook conditions (Table 6.41) the fall arrest force and deceleration distance (Table 6.42), and the wear and fatigue of the system’s components (Table 6.43).

<table>
<thead>
<tr>
<th>Fall arrest falling distance</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger than 6 ft (1.8 m)</td>
<td>Prob 52</td>
</tr>
<tr>
<td>Larger than distance to ground or nearest surface</td>
<td>Prob 53</td>
</tr>
<tr>
<td>Less than 6 ft (1.8 m)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.37: Decision table for fall arrest falling distance

<table>
<thead>
<tr>
<th>Anchorage Point</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>can withstand 5000 pounds (22.2 kN)</td>
<td>o.k.</td>
</tr>
<tr>
<td>cannot withstand 5000 pounds (22.2 kN)</td>
<td>Prob 54</td>
</tr>
<tr>
<td>guardrail and hoist device used as anchor</td>
<td>Prob 55</td>
</tr>
</tbody>
</table>

Table 6.38: Decision table for fall arrest anchorage point

<table>
<thead>
<tr>
<th>Lifeline and lanyard strength larger than 5000 pounds (22.2 kN)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 56</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.39: Decision table for fall arrest lifeline and lanyard strength
Deerings and snaphooks can withstand a 3600 lb. (16 kN) load

<table>
<thead>
<tr>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yes</strong></td>
</tr>
<tr>
<td><strong>No</strong></td>
</tr>
<tr>
<td><strong>Don't know</strong></td>
</tr>
</tbody>
</table>

Table 6.40: Decision table for fall arrest deerings and snaphooks strength

<table>
<thead>
<tr>
<th>Snaphooks conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snap hook sizes not compatible with connected members</td>
<td>Prob 58</td>
</tr>
<tr>
<td>Snap hook connected directly to webbing or rope or wire rope</td>
<td>Prob 59</td>
</tr>
<tr>
<td>Snap hook connected to each other</td>
<td>Prob 60</td>
</tr>
<tr>
<td>Two snap hooks connected to the same deerings</td>
<td>Prob 61</td>
</tr>
<tr>
<td>Snap hook connected to a horizontal lifeline</td>
<td>Prob 62</td>
</tr>
</tbody>
</table>

Table 6.41: Decision table for Fall arrest snaphook conditions

<table>
<thead>
<tr>
<th>Force and deceleration distance smaller than 1800 pounds (8 kN) and 3.5 feet (1.07 m)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yes</strong></td>
<td>o.k.</td>
</tr>
<tr>
<td><strong>No</strong></td>
<td>Prob 63</td>
</tr>
<tr>
<td><strong>Don't know</strong></td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.42: Decision table for fall arrest force and deceleration distance

<table>
<thead>
<tr>
<th>Did the system components showed any signs of wear</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yes</strong></td>
<td>Prob 63</td>
</tr>
<tr>
<td><strong>No</strong></td>
<td>o.k.</td>
</tr>
<tr>
<td><strong>Don't know</strong></td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.43: Decision table for fall arrest components wear
Lifeline designed and installed under engineer supervision

<table>
<thead>
<tr>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Don’t know</td>
</tr>
</tbody>
</table>

Table 6.44: Decision table for fall arrest horizontal lifeline installation

Locking snaphooks used for horizontal lifeline

<table>
<thead>
<tr>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Don’t know</td>
</tr>
</tbody>
</table>

Table 6.45: Decision table for fall arrest horizontal lifeline locking snaphooks

Did the device limit the worker’s free fall to less than 2 feet (0.61 m)

<table>
<thead>
<tr>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Don’t know</td>
</tr>
</tbody>
</table>

Table 6.46: Decision table for fall arrest self-retracting line free falling distance

If a safety net system was installed, the program will check the falling distance to the net and the net’s outward extension (Table 6.47). If the falling distance is less than five feet (1.5 m), then the outward extension should be eight feet (2.4 m). If the falling
distance is between 5 and 10 feet (1.5 and 3 m), then the extension should be at least 10 feet (3 m). Finally, if the falling distance is between 10 and 30 feet (3 and 9.1 m), the extension should be 13 feet (3.96 m). If the falling distance is larger than thirty feet (9.1 m), it is considered a problem because the worker may injure itself.

Next, the system will ask the user about whether the clearance underneath the net is adequate to prevent the net from hitting the ground or nearest surface (Table 6.48). The program also checks whether debris is regularly cleared from the net (Table 6.49). If the user answers that the net is not cleared regularly, this is considered a problem which may result in workers injuries (Prob 69). After that, the program evaluates whether the net was fastened well to its supports and its panels well connected to each other (Decision Tables 6.50 and 6.51). Otherwise the net or one of its sections may fall apart under the falling worker impact. Finally, the system checks if the original net materials were strong enough to support the worker impact (Table 6.52) and if they are still strong enough or they show any signs of wear, break down, or fatigue (Table 6.53).

<table>
<thead>
<tr>
<th>Vertical distance from surface to net</th>
<th>Safety net outward extension (ft)</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 ft (1.5 m)</td>
<td>&gt; 8 ft (2.4 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>&lt; 5 ft (1.5 m)</td>
<td>&lt;= 8 ft (2.4 m)</td>
<td>Prob 67</td>
</tr>
<tr>
<td>5 - 10 ft (1.5 - 3 m)</td>
<td>&gt; 10 ft (3 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>5 - 10 ft (1.5 - 3 m)</td>
<td>&lt;= 10 ft (3 m)</td>
<td>Prob 67</td>
</tr>
<tr>
<td>10 - 30 ft (3 - 9.1 m)</td>
<td>&gt; 13 ft (3.96 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>10 - 30 ft (3 - 9.1 m)</td>
<td>&lt;= 13 ft (3.96 m)</td>
<td>Prob 67</td>
</tr>
<tr>
<td>&gt; 30 ft (9.1 m)</td>
<td>----</td>
<td>Prob 68</td>
</tr>
</tbody>
</table>

Table 6.47: Decision table for safety net distances
<table>
<thead>
<tr>
<th>Safety Net debris cleared regularly from net</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 69</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.48: Decision table for safety net debris

<table>
<thead>
<tr>
<th>Clearance underneath the net adequate</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 70</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.49: Decision table for safety net clearance

<table>
<thead>
<tr>
<th>Safety net well fastened to supports</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 71</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.50: Decision table for safety net fastened to support

<table>
<thead>
<tr>
<th>Net panels well connected to each other</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 72</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.51: Decision table for safety net panels connection
The controlled access zones (CAZ) are only used when none of the devices discussed above can be used and under certain specific conditions. If none of these conditions is present, the CAZ should not have been used (Table 6.54). In addition, the distance between the CAZ and the floor edge should be within the ranges allowed by OSHA otherwise, the area enclosed may be too small (Prob 83) or too large (Prob 84). Furthermore, the CAZ should be installed parallel to the edge, should protect the entire edge of the floor, and should be connected at each side to a guardrail or a side wall (Table 6.56). As with the warning line, the CAZ line should be erected at certain height to be effective (Table 6.57). If it is too high it may not prevent workers from entering the restricted area. If too low, may cause distracted workers to trip. The system also considers
the line strength (Table 6.58) and the wear or fatigue it shows (Table 6.59). Finally, if the CAZ is used, a safety monitor should be in the work zone (Prob 90). This monitor should have all employees within visual and audio range (Table 6.61) and his or her only function should be to monitor the workers safety.

<table>
<thead>
<tr>
<th>CAZ conditions</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading edge work</td>
<td>o.k.</td>
</tr>
<tr>
<td>Edge overhand bricklaying work</td>
<td>o.k.</td>
</tr>
<tr>
<td>Edge precast concrete erection work</td>
<td>o.k.</td>
</tr>
<tr>
<td>Use of conventional fall protection devices was</td>
<td>o.k.</td>
</tr>
<tr>
<td>unfeasible</td>
<td></td>
</tr>
<tr>
<td>Use of conventional fall protection devices was</td>
<td>o.k.</td>
</tr>
<tr>
<td>more hazardous</td>
<td></td>
</tr>
<tr>
<td>None of the above</td>
<td>Prob 82</td>
</tr>
</tbody>
</table>

Table 6.54: Decision table for CAZ conditions

<table>
<thead>
<tr>
<th>CAZ distance to edge</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too short</td>
<td>Prob 83</td>
</tr>
<tr>
<td>Too large</td>
<td>Prob 84</td>
</tr>
<tr>
<td>Adequate</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.55: Decision table for CAZ edge distance

<table>
<thead>
<tr>
<th>Adequate CAZ installation</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 85</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.56: Decision table for CAZ installation

270
### CAZ elevations

<table>
<thead>
<tr>
<th>CAZ elevations</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too high</td>
<td>Prob 86</td>
</tr>
<tr>
<td>Too low</td>
<td>Prob 87</td>
</tr>
<tr>
<td>Adequate</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.57: Decision table for CAZ elevations

### CAZ strength is adequate

<table>
<thead>
<tr>
<th>CAZ strength is adequate</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 88</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.58: Decision table for CAZ strength

### CAZ signs of wear or fatigue

<table>
<thead>
<tr>
<th>CAZ signs of wear or fatigue</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 89</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.59: Decision table for CAZ wear

### All employees within monitor visual and audio range

<table>
<thead>
<tr>
<th>All employees within monitor visual and audio range</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 91</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.60: Decision table for CAZ monitor range
Monitor only function is monitoring employee safety

<table>
<thead>
<tr>
<th></th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 92</td>
</tr>
<tr>
<td>Don't know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.61: Decision table for CAZ monitor functions

Other fall protection adequate strength

<table>
<thead>
<tr>
<th></th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 93</td>
</tr>
<tr>
<td>Don't know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.62: Decision table for other fall protection device strength

Signs of wear or fatigue

<table>
<thead>
<tr>
<th></th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 94</td>
</tr>
<tr>
<td>Don't know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table 6.63: Decision table for other fall protection device wear

Finally, if none of the previously listed devices were installed in the site, then the program will allow the user to specify the “other device” option which will be evaluated as to whether the device is adequate according to OSHA standards (Table 6.62) and the materials used to build it did not show any defects like corrosion or wear (Table 6.63).
Figure 6.2: Decision Structure to Evaluate Floor Edge Component
Figure 6.2 (Continued)

Guardrail Posts
Materials?

Wood?

N

Table 6.9

Pipe?

Y

D. Table 6.20

Str. Steel?

Y

D. Table 6.21

Other?

D. Table 6.22

Rails Adequately Secured to Posts?

D. Table 6.23

Posts Adequately Secured to Floor?

D. Table 6.24

Guardrail System Materials Wear?

D. Table 6.25

CP Horizontal Distance from Floor

D. Table 6.26

CP Floor Location with respect to Floor?

D. Table 6.27

Catch Platform System Installed?

Y

Catch Platform Components Wear?

Table 6.21

Catch Platform Guardrail?

N

Prob 31

Catch Platform Installation?

D. Table 6.28

Catch Platform Strength?

D. Table 6.29

Scaffold Grade Wood or Sheet Metal Floor?

Table 6.20

To be continued
Figure 6.2 (Continued)

CPG Component Missing?
Table 6.22

CP Guardrail Rails Elevations?
Table 6.23

CP Guardrail Posts Spacing?
Table 6.24

CP Guardrail Rail Materials?

Wood?
Y Table 6.25 & 26

Pipe?
N

Y Table 6.27

Str. Steel?
N

Y Table 6.28

Other?

Y Table 6.29

CP Guardrail Posts Materials?

Wood?
Y Table 6.30

Pipe?
N

Y Table 6.31

Str. Steel?
N

Y Table 6.32

Other?

Y Table 6.33

CP Rails Adequately Secured to Posts?
Table 6.34

CP Guardrail System Material? Missing?
Table 6.36

CP Guardrail Posts Adequately Secured to Platform?
Table 6.35

To be continued
Figure 6.2 (Continued)

- **Fall Arrest System Installed?**
  - N
  - Y
    - **Vertical Lifeline and Lanyard?**
      - N
      - Y
        - **Distance to Ground? Falling Distance?**
          - Table 6.37
          - Y
            - **Anchorage Point Strength?**
              - Table 6.38
              - N
                - N
              - Y
                - **Lifeline and Lanyard Strength?**
                  - Table 6.39
                  - Y
                    - **Deerings and Snaphooks Strength?**
                      - Table 6.40
                      - N
                        - N
                      - Y
                        - **Locking Snaphooks?**
                          - Table 6.41
                          - Y
                            - **Distance to Ground? Falling Distance?**
                              - Table 6.37
                              - N
                                - N
                              - Y
                                - **Arrest Force? Deceleration Distance?**
                                  - Table 6.42
                                  - N
                                    - N
                                  - Y
                                    - **Wear and Fatigue?**
                                      - Table 6.43
                                      - N
                                        - N
                                      - Y
                                        - **Arrest Force? Deceleration Distance?**
                                          - Table 6.42
                                          - N
                                            - N
                                          - Y
                                            - **Horizontal Lifeline?**
                                              - Y
                                                - **Wear and Fatigue?**
                                                  - Table 6.43
                                                  - N
                                                    - N
                                                  - Y
                                                    - **Deerings and Snaphooks Strength?**
                                                      - Table 6.40
                                                      - N
                                                        - N
                                                      - Y
                                                        - **Arrest Force? Deceleration Distance?**
                                                          - Table 6.42
                                                          - N
                                                            - N
                                                          - Y
                                                            - **Free Falling Distance Allowed?**
                                                              - Table 6.46
                                                              - N
                                                                - N
                                                              - Y
                                                                - **Wear and Fatigue?**
                                                                  - Table 6.43
                                                                  - N
                                                                    - N
                                                                  - Y
                                                                    - **Horizontal Lifeline Locking Snaphooks?**
                                                                      - Table 6.45
                                                                      - N
                                                                        - N
                                                                      - Y
                                                                        - **Lifeline Strength?**
                                                                          - Table 6.39
                                                                          - N
                                                                            - N
                                                                          - Y
                                                                            - **To be continued**
Figure 6.2 (Continued)

Safety Net System Installed?

- Vertical Dist. to Net? Safety Net Extension?
  - Table 6.47

- Safety Net Clearance Underneath?
  - Table 6.49

- Safety Net Clear from Debris?
  - Table 6.48

- Safety Net Fully Fastened?
  - Tables 6.50 & 51

- Safety Net Strength?
  - Table 6.52

Safety Net Materials Wear?

- Controlled Access Zone Installed?

- Safety Net Materials Wear?
  - Dec. Table III-4.53

- Controlled Access Zone Conditions?
  - Table 6.54

- CAZ Distance to Edge?
  - Table 6.55

- CAZ Installation?
  - Dec. Table III-4.56

- CAZ Line Elevation?
  - Table 6.57

- Controlled Access Line Strength?
  - Table 6.58

To be continued
Figure 6.2 (Continued)

- Controlled Access Zone Wear? (Table 6.59)
- CAZ Safety Monitor? (Table 6.60)
- CAZ Safety Monitor Functions? (Table 6.61)
- Other Device Installed?
  - Y (Final Conclusion)
  - N
- Device Adequate for Fall Protection? (Table 6.62)
- Device Showed signs of Wear? (Table 6.63)
- Prob 88
7.1 Introduction

This chapter discusses the various aspects of the fall design and planning module of SAFETY FIRST (Figure 7.1). It starts by providing a brief background of the status of design and planning in construction. The focus is on the Construction Design and Management (CDM) regulations which came into effect in 1995 in Europe. These
regulations place part of the safety burden on the designer (i.e., consider potential hazards associated with their design alternatives and provide the contractor with a list of the hazards left in the design). The next section discusses the design and planning factors identified in this study with regard to safety. Finally, the last section discusses the decision structure used to organize these factors and incorporate them into the system's knowledge base.

7.2 Introduction to Design and Planning in Construction

Currently, the contractor is the party in the construction process bearing the responsibility for safety during the construction stages of the project. However, a study by the Health and Safety Executive (HSE) indicates that a large percentage of the injuries and deaths in construction are traceable to design decisions and planning problems [Churcher and Alwani-Starr 1996]. Because of these problems, in 1994, the European Community adopted the Construction Design and Management (CDM) regulations. Under these regulations, all parties (e.g., owner, designer, and contractors) to a project have responsibilities with respect to safety. As a consequence, it is expected that safety will be taken into account at the project's conception, through its construction, and during subsequent maintenance work.

As a result of the CDM regulations [Churcher and Alwani-Starr 1996, Munro 1996], the owner has the responsibility to appoint a 'planning supervisor' which has the responsibility of coordinating health and safety matters before, during, and after construction. During the design and planning stage this supervisor will monitor the health
and safety aspects of the design, advise the owner as to the allocation of resources to safety, and ensure the creation of a health and safety plan to be presented to the contractor. The safety plan is initially developed at the design stage and prior to bidding so that the contractors are aware of the residual hazards that need to be managed during construction.

As for the designer, for each potential design option he or she must consider the potential health and safety hazards involved (i.e., during construction and maintenance), consider the risks associated with them, and whenever possible choose the safest alternative solution. Finally, once a specific design has been chosen, the designer must identify the significant or unusual remaining hazards, bring them to the contractors attention, and provide suggestions as to how to handle them (though the final decision on this aspect is the contractor’s).

Given these responsibilities placed on the designer, the objective of this chapter is to identify fall-related design and planning aspects of a multi-story building construction project. These knowledge aspects have been incorporated into the planning and design module of the SAFETY FIRST system. The objective of this module is to provide the designer with a consultation tool which will assist him or her to recognize potential design hazards that could lead to falls during the construction and maintenance stages. The system will ask the designer to enter various information about the structure design and will identify design aspects the designer may want to reconsider. Further, if the original design is maintained, in its recommendation, the system will provide a list of planing factors that the contractor may want to consider to reduce the likelihood of falls.
As with the development for the other expert system modules, the research method for this module included the knowledge acquisition, knowledge representation, system development, and system validation stages. Unlike the previous expert systems, the knowledge used in this module is not closely related to the fault tree structures discussed on Chapter 4. The knowledge was acquired largely from experts through a knowledge acquisition process, such as the one discussed on Chapter 5. Little research has been done in this area of fall protection; however, Hinze [1996] and Ellis [1994] have discussed some general design and planning aspects that could improve safety in construction.

This chapter discusses the design and planning aspects identified in this research and then discusses how this aspects were organized into a decision structure to detect potential problem areas in the design and provide certain areas where planning may overcome some fall related potential problems.

7.3 Fall Safety Design and Planning in Construction

As mentioned before, the designer has to consider his or her design and foresee the potential hazards that may arise from that design. In this study, we limit the scope of the designer to detecting potential fall hazards that may arise during construction or maintenance work as a result of the design. The following are the major design factors identified:

1. Whenever possible, in terms of constructability and future maintenance, it is preferable to have flat or low sloped roofing structures. In terms of fall hazards, the dangers
associated with the construction of a flat roof are smaller than those associated with pitched or steep sloped roofs.

2. Perimeter or parapet walls have been commonly used in flat roofs; however, most of these walls are about 30 inches high. In order for these walls to be effective in guarding the edge from falls, experts suggest to increase the height of these walls to 39 inches (1020 mm) [Hinze 1997]. Further, parapet walls could also be effective in guarding steep sloped roof structures. The presence of these walls would make future construction and maintenance on the roof. A factor to consider if parapet walls are designed on pitched roofs is increasing the load bearing capacity of the roof to handle potential snow accumulation, or designing a way to prevent such accumulation on the roof.

3. In order to prevent falls during maintenance work, steep sloped roof structures should be designed to have an access point on the interior of the roof (i.e., not from the edge). Further, this access point should have an anchorage point accessible for the worker to tie up before stepping on the roof.

4. The design roof structures for buildings with more than 3 stories (i.e., experts opinion) should include permanent anchorage points that can be used for future maintenance work of the building or during the construction stages. These anchorage points should be able to withstand a minimum load of 5400 pounds, be corrosion resistant, and whenever possible bolted or attached to a load bearing structural component of the structure.
5. For structural steel framed structures, the column design could incorporate built-in anchor points (e.g., ears) which could be used by steel erectors to tie up. Further, the columns could also have built-in holes at 42 inches (1100 mm) and 21 inches (550 mm) high to accommodate the erection of a wire rail system on the floor perimeter [Hinze 1997].

6. Finally, prefabricated wall structures could be designed in to reduce the exposure time and the potential for falls and falling objects [Hinze 1997]. It has been suggested that this method of erection is cost effective and faster than traditional practices.

In addition, the designer still should be able to identify the residual hazards still existent in the design and provide suggestions to deal with these hazards. The following are the major planning considerations identified in this study:

1. If the roofing structure of the building has permanent anchorage points designed in, they should be installed as early as possible in the construction process, so that they can be used at later construction stages.

2. Whenever any work has to be performed on a steep roof not protected by a parapet wall, a temporary anchorage structure (e.g., horizontal lifeline) should be set up as a tie up point for workers. A scaffolding structure (e.g., form scaffolding) erected on the roof perimeter could also be used to protect worker from falling. This structure could also be used as a temporary working surface.

3. The load bearing capacity and condition of the roof must be considered before bringing working materials into the roof. This is to prevent roof failures (a major cause of worker falls from roofs). This is especially significant in the case when maintenance
work is being performed in the roof due to water leaks which could have affected the roof’s strength.

4. A quick way to set up a guardrail system for a steel framed building is to tag weld washers to the inner part of the column before their installation. These washers should be welded at 42 inches (1100 mm) and 21 inches (550 mm) high to accommodate the erection of a wire rail system as soon as the steel floor deck is in place. In order to prevent sagging of the wire rail, U bolts could be tied to the wire rail besides the washers.

5. Materials should be stored away from floor and roof edges and holes in order to prevent falling object hazards.

6. Loading zones on the floor or roof edges (i.e., usually not protected by guardrail) should be guarded by other fall safety devices such as safety nets or fall arrest systems. If the anchor point available is not able to withstand the 5000 pounds requirement, a restrain or tethering system which stops the tied up worker from getting past the edge could be used.

7. In order to reduce the exposure time of workers while erecting edge guardrails (i.e., wood, pipe or steel), the major components (posts, top rail and mid rail) of the guardrail should be assembled before hand on the interior of the floor.

8. For steel erection, whenever possible, the use of mobile scaffolding equipment (hydraulic lift baskets, scissors lifts) is recommended as a working platform during connection procedures. If this equipment is not available, ladders are a better option to climbing the column to reach the connection point. Further, seat lugs installed on the
columns to support the beam during steel connection procedures can facilitate the process and reduce the risks associated with it. Finally, a fall arrest system using a combination of horizontal lifelines installed on the beams on the ground before lifting them in place and the wearing of two harnesses has proven effective (i.e., one harness is attached to the current beam. To move to a different beam, worker attaches a second harness to a new lifeline and disconnects the harness from the previous beam).

9. Scaffold structures which minimize the number of components to assemble and already have a prefabricated guardrail structure installed are more likely to prevent erection and installation problems. For example, a scaffolding structure where the guardrail is an essential part of the structural integrity of the structure, forces the contractor to install the guardrail in order to guarantee the structures vertical and lateral load bearing capacity.

10. Whenever the worker needs both hands to perform an overhead job, modular or mobile scaffolds (e.g., scissors lifts) are preferable to portable ladders. Ladders in order to be used properly require the worker to maintain three contact points. This is not possible if the worker must use both hands to perform his or her job.

11. All floor holes should be guarded by a cover, unless the hole is used as an access point to the floor; in which case, the hole should be protected by a guardrail system. All wall openings should also be protected by a guardrail system.

12. Finally, the contractor should have safety policies to address general safety problems that could affect fall safety performance. For example, housekeeping, personal protective equipment, worker training, and worker health, among others.
7.4 Representation of Design and Planning Knowledge

The knowledge discussed above was organized in a decision structure (Figure 7.2) which was later used to develop the knowledge base of the design and planning expert system module. The system starts up by checking the type of roof structure used in the design of the building. If the structure is a pitched roof, the system will check if a low-sloped roof would perform the same functions for about the same cost. If this is the case the program will suggest the designer to consider using a flat roof in the design (Design 1). If a flat roof is not a viable option, the system will check the design method to access the roof after construction. A good design will provide an access way from the interior of the structure (Design 2). Further, if such access is provided, the design should include an anchor point for workers to tie up (Design 3) and this anchor should be accessible to the worker before he or she walks on the roof (Design 4). Finally, the system will check if the pitched roof had a perimeter wall to guard its edge (Design 7) and it was higher than 39 inches (1020 mm) (Design 8). If no perimeter wall exists, the system will also suggest the use of horizontal lines during roof maintenance work (Planning 2). If the roof structure is a flat roof, the program will again check if a parapet wall was guarding it (Design 5) and the wall was 39 inches (1020 mm) or higher (Design 6).

Next, the system will check if the building structure being designed is more than 3 stories high. In this case, the system will check if permanent perimeter anchors have been designed for future maintenance work (Design 9) and their strength is larger than 5400 pounds (Design 10). If anchors have been designed in the project, the system will
recommend that these structures be erected early on so that they can be used during construction operations (Planning 2).

Further, the system will check if the building frame is concrete-based or steel based. If it is structural steel-framed, the system will check if the designer considered building in anchor points on the column (Design 11) or building guardrail holes on the web of the column (Design 12). For a steel framed structure, the system will also recommend the use of washers tag welded on the column before erection as a quick and safe guardrail erection method (Planning 4). Otherwise, the system will recommend the use of mobile working platforms or a horizontal fall arrest system to assemble the steel structure (Planning 8).

Next, the system will check if the building design includes pre-fabricated walls. If it does not, the system will ask the designer to evaluate whether these walls could be incorporated in the design without sacrificing functionality, aesthetics, or cost. If the answer is ‘yes,’ the system would recommend their use (Design 13). Their installation reduces fall exposure time and falling object hazards. Otherwise, the system will recommend the contractor to pre-assemble the main components of the guardrail before installing it on the edge (Planning 7).

Finally, the system will provide a list of planning suggestions the contractor may use to deal with some of the remaining fall hazards: considering the roof load bearing capacity before sending workers or materials to the roof (Planning 3), storing materials away from the edges (Planning 5), protecting loading zones with a fall arrest or safety net (Planning 6), using modular scaffolding structures which minimize assembling (Planning
9), using scaffolds instead of portable ladders whenever possible (Planning 10), guarding holes with covers (Planning 11), and having an overall safety policy to deal with other general safety problems (Planning 12).
Figure 7.2: Decision Structure for Design and Planning to Avoid Falls
Figure 7.2 (Continued)

- Building more than 3 stories high?
  - Yes → Built in Anchors in Column?
  - No → Design 11

- Permanent Roof Anchors?
  - Yes → Built in Holes for Guardrail?
  - No → Design 9 Planning 2

- Adequate Strength?
  - Yes → Design 10
  - No → Planning 1

- Steel Framed Structure?
  - Yes → Planning 8
  - No → Design 12 Planning 4

To be continued
Figure 7.2 (Continued)
8.1 Introduction

As discussed on the previous chapters, three of the modules of SAFETY FIRST have been designed as expert systems: investigation, evaluation, and design and planning modules. The knowledge contained in each of these modules varies according to its expected function. The knowledge structure for each of these modules has already been discussed in Chapters 5, 6, and 7. These structures encompass the knowledge needed to develop the expert systems above. This knowledge is stored in the system's knowledge base in the form of facts (classes, instances and attributes) which describe aspects of the domain knowledge and production rules (IF-THEN rules) which tell the system what information can be obtained from such facts. The system, through the inference engine or inference mechanism (i.e., forward chaining), combines the rules and facts in the knowledge base to reach a conclusion, much the same way experts reach a conclusion from available facts and previous experiences in dealing with similar problems. In order for the system to reach a conclusion, it must have specific information about the domain problem (evidence). This information is obtained from the system's user through the user interface. In addition to obtaining information from the user, the user interface acts as the
contact between the expert system and the user; therefore, through it the system's user can get explanations regarding the information required, terms used, or conclusions obtained. This chapter discusses the architecture and the major components (i.e., knowledge base, inference engine, user interface, and external files interface) of the expert system modules of SAFETY FIRST.

8.2 Implementation Tool

As discussed in Chapter 5 (i.e., introduction to expert systems), LISP and PROLOG are the most widely accepted products to develop AI applications given that they provide the knowledge engineer the largest flexibility to compute with symbolic expressions rather than numbers, write rules, design interfaces, and so on. However, these tools require an extensive computer background in order to take advantage of all the features offered by them. The other group of tools available for the development of expert systems are the expert system shells which are environments built in high level language in order to facilitate the building process. Expert system shells can be regarded as "a reasoning system out of which all the knowledge has been emptied" [Parsaye, 1988] and which provides the knowledge engineer who has a basic computer background with all the facilities required for building a knowledge base. In addition of allowing development by non-programmers, expert system shells have the following advantages: low initial cost, run on standard personal computers, allow fast development, and allow the production of attractive and user-friendly interfaces.
A good expert system shell provides the facilities to assist the developer in the creation of the knowledge base containing the domain specific facts and heuristic knowledge. In addition, it should at least contain inference and user interface mechanisms. The inference mechanism controls the reasoning process of the expert system so that given certain explicit knowledge, it can reach specific conclusions by using varying inference strategies (e.g., backward or forward chaining). The user interface mechanism supports the users' consultation with the expert system by prompting them for the information, displaying and explaining conclusions, and providing other explanation facilities. Other important factors in an expert system shell are the ease of translation from language into computer code, the availability of a debugging tool, and the flexibility of the program regarding the addition of new facts and rules.

Given the factors mentioned above, we decided to use the LEVEL5 v. 3.5 expert system shell (professional edition) to develop SAFETY FIRST [Information Builders 1993, 1993a]. Out of the shells surveyed, this shell proved to be the one within a reasonable price range which fulfilled all of our requirements of providing all the necessary facilities to assist the developer in the construction of the knowledge base, and allowing for the development of a user-friendly program. The following are some of the properties of the LEVEL5 v. 3.5 shell:

- Windows based environment. The most widely used operating system.
- Simple and easy to understand syntax.
- Object-oriented programming.
- Designs tools for point and click design.
• Library of objects to use in the application.
• Debugging tools.
• Interface with other windows application programs.
• It does not require the user to do memory management.
• It allows for the creation of a runtime version of the system.

With this expert system shell, the SAFETY FIRST program was implemented. The next section discusses the architecture of the expert system modules of the program.

8.3 Expert Systems Architecture

The expert system modules of SAFETY FIRST consist of five major components: the knowledge base, the inference engine, the user interface, the external files interface, and the external files. The first four components are contained within the Level-5 Object expert system shell selected to develop the system.

8.3.1 Knowledge Base

In the realm of artificial intelligence, Harmon and Sawyer [1990] define knowledge as “an integrated collection of facts and relationships which, when exercised, produces competent performance.” It can be classified into procedural knowledge, which is composed of a specific set of steps that can be followed to achieve a specific result, and declarative knowledge, which only concerns the logical or empirical relationships between two or more terms. For example, in conventional data processing, a program would be the procedural knowledge while the data in a database would be the declarative knowledge.
Figure 8.1: Architecture of the SAFETY FIRST’s Expert System Modules
Declarative knowledge includes both definitional and heuristic knowledge. “Definitional relationships are defined by common agreement about how words are to be used” [Harmon and Sawyer 1990]. On the other hand, a heuristic is a rule-of-thumb that allows the assignment of a value to or a judgment of a variable that would otherwise be unpredictable. Declarative knowledge is used by experts to reach decisions. Therefore, it is also the knowledge used by expert systems to handle complex and vaguely defined problems which conventional programs cannot handle easily.

An expert system usually stores the declarative knowledge in its knowledge base, while the knowledge code that controls its inference and search procedures is kept in an inference engine which actually is “an algorithm that dynamically directs or controls the system when it searches its knowledge base” [Harmon and Sawyer 1990]. This separation of declarative and inference knowledge guarantees that the system can respond in a more flexible manner. Furthermore, it lets the developer focus on getting the declarative knowledge (expert knowledge) that goes in the knowledge base, leaving the development of a specific search strategy to the inference mechanism (provided by expert system shells).

The knowledge base of each of the SAFETY FIRST's expert systems (i.e., investigation, evaluation, and design and planning) is based on the declarative knowledge represented on the decisions structures discussed on Chapters 5, 6, and 7. This knowledge encompasses both heuristic knowledge from experts and written knowledge from literature and OSHA codes.
The development of these decision structures facilitated the conversion of the knowledge into classes or instances with certain attributes associated to them, and production rules which represented the logical or empirical relationships among the events or causes are represented in the knowledge base. All of the events and causes in the are represented as either classes, attributes, or instances in the knowledge base. Further, in order to trigger certain functions or properties, the program uses chunks of procedural codes which are stored inside "When changed" methods. Therefore, the knowledge representation schemes that used for the development of the expert system modules are objects (i.e., classes or instances), production rules (i.e., named demons in Level-5), and when changed methods. Each of these components will be discussed next.

8.3.1.1 Objects

Level-5 is an object oriented expert system shell. It allows the creation of classes, instances and attributes to group the knowledge. A class is a group of attributes that describes a given object with similar characteristics, such as the same attributes and methods. An instance is a specific example of a given class. Attributes are the specific characteristics that define the object.

Each object or frame is a block of data that is more or less independent of any other block of data in the program application. An object contains both data and procedures (methods) belonging to it and pointers to one or more of its parents containing data or procedures that the object can access if necessary. Furthermore, each block of information within the frame is contained in specific slots. Examples of data are attributes
typically associated with the object, while methods are ways for the object to request or provide information from other objects.

A very specific property of object-oriented programs is that of "inheritance" which allows objects to acquire or inherit information from other objects to which they are linked. The process works as follows: "when an object receives a 'message' that requests it to provide data about itself, it begins by checking for the necessary data within its 'unique part.' If it fails to find it there, it then checks with its inherited part, thus turning to its parents to see if they contain the data" [Harmon and Sawyer 1990].

Object-oriented systems have the advantage of being simple in grouping data according to its natural properties. By doing this, these systems also provide a way to organize knowledge into modules which can be used without modification in different applications. Given its modularity, the relationship among data within the system will be clearer and therefore easier to maintain.

For the SAFETY FIRST expert systems, each node in the decision structure is converted into a class or an instance of a class. The knowledge was grouped into the enabling, triggering, support-related, and conditioning classes. Instances of these classes were the various attributes associated with each of these classes. For example, Illegal Drugs Use is an instance of the Enabling class. The next step was to identify the characteristics and methods needed to define each object. For example, whether the knowledge is inferable (it can be reasoned by the system from other knowledge) or observable (it can be obtained by the user from eye witnesses or by inspection), the type of attribute needed to define the knowledge (e.g., numeric, string, compound, multivalued)
and the values these attributes may take (e.g., yes/no/don't know compound), the default values and units this attribute may take (e.g., guardrail wood cross-section is assumed to be 2 by 4 inches), and the methods that will be needed by the class.

Figure 8.2 shows an example of a generic object developed for the SAFETY FIRST experts systems. It is made up by the following attributes: NAME (string) to identify the individual object instance, PROMPT (string) that stores the question to be given to the user in order to get his or her input, INPUT (Y/N/DK compound) which depends on the object type is the attribute that will collect an store the value, ILLUSTRATION (picture or string) contains the graphic associated to the current object, KEYWORD (string) will store the key word in the question, KEYWORD DESCRIPTOR (string) will store the information about the key word, WHY EXPLANATION (string) will store the reason as to why the current knowledge is needed, and QUESTION EXPLANATION (string) contains the information about how to answer the question associated to the current object. The object also has the following methods associated to it: WHY (simple) it will trigger an when changed method to display the information contained on the WHY EXPLANATION attribute, KEYWORD FIRE will trigger a method to display the information about the current keyword, and INPUT CHECK will trigger a method to query the user as to the value of this attribute.
8.3.1.2 Production Rules

Rule-based knowledge representation is the most popular tool for coding knowledge into a knowledge base. People tend to express their knowledge in the form of rules. In fact, when explaining their jobs, experts frequently use statements about “what to do” under certain conditions. These statements are represented in terms of “IF (condition) THEN (action)” rules. The “IF” section of the rule is alluded to as the premise, antecedent, or condition side, while the “THEN” section is referred as the conclusion, consequent, or action side. Given a real condition, the inference engine tries to match it with one of the “IF” conditions in the rules of the knowledge base. If this is done then the action on the “THEN” side of the rule occurs. Examples of what the action may implicate are opening and checking other rules, executing certain command(s), and so on.
A rule-based system has the advantage of "being easily modified (modularity) and having a consistent rule-base structure (uniformity). The knowledge engineer can change rules independent of their relationship to other rules. The change may affect the performance of the system but will not affect the knowledge encoded in other rules" [Carrico et al. 1989]. However, if very simple rules are used, they can also be disadvantageous in that a rigid form of representation may result. This problem can be prevented by using a highly modular approach, each rule behaving like an independent piece of knowledge. However, there is an inverse relationship between a program's flexibility and its running time, high modularity may lead to problems with a program's execution time and vice versa. Furthermore, in large and complex systems that have been updated several times, conflicts between rules may occur in specific cases.

The SAFETY FIRST system uses a forward chaining inference engine; hence, if the antecedent of the rule is true then the consequence of it is inferred to be true. The consequence will provide new information to be searched and which eventually will lead to a conclusion. In SAFETY FIRST there are two main types of production rules. The first type is used as a message passing tool to transfer control among the objects in the knowledge base. The second is used by the system to make inferences and reach a final conclusion. The production rules are of the following form:

IF (antecedent) THEN (consequence)

In essence, the first kind of rules store the objects' knowledge about the world. These rules were established by converting the decision trees' links and decision tables
rows into IF-THEN statements used by the objects to transfer control among each other. That is, until a conclusion is found or the program has run out of options to search. The following is an example of this kind of rule:

\[
\text{IF input OF floor collapse is Yes THEN input check OF floor enabling is TRUE} \\
\text{IF input OF floor enabling is No THEN input check OF floor triggering is TRUE} \\
\text{IF input OF floor triggering is Yes THEN finished OF consultation is TRUE}
\]

In this example, the system will first check if the fall was caused by the floor collapse. If it was, then it will fire the first rule, which will transfer control to the floor enabling object. Thus, the program will query the user as to the possibility of a floor enabling problem causing the collapse. If the answer to this query was no, the second rule is fired and control is transferred to the floor triggering object. Finally, if the user indicates that a floor triggering cause was the cause of the collapse the consultation will stop (i.e., finished OF the consultation object is set equal to TRUE).

Once a consultation has been completed (i.e., the finished OF consultation is set equal to TRUE), the second kind of rules will be used to infer the final conclusion. The following is an example of three rules fired in succession by the system:

\[
\text{IF the wood top rail material height is less than 4 inches AND the wood top rail material width is less than 2 inches THEN the top rail cross-section is undersized} \\
\text{IF the top rail cross-section is undersized THEN the top rail strength is not adequate}
\]
IF the top rail strength is not adequate AND the top rail collapsed under worker impact THEN the conditioning cause of fall is the top rails lack of strength.

In this case, if the first rule is fired, the program will conclude that the top rail cross-section is undersized, and as a consequence of the second rule, infer that the top rail strength is not adequate. Finally, if the user indicates that the top rail component of the guardrail collapsed under the worker impact, the system will conclude that the lack of strength in the top rail was a conditioning cause of the fall.

In cases where more than one rule can be fired at a given time (i.e., the antecedent side of several rules match the world conditions), the system's inference engine will control the way the rules are fired. Only the first rule may be fired or all of them may be fired.

8.3.1.3 When Changed Methods

Also referred to as “When modified” or “When accessed” functions, they are “functions which are not invoked explicitly, but hibernate until a pre-defined condition occurs. This technique allows one to represent knowledge at a global level without following the protocol of rules within the knowledge system” [Carrico et al. 1989]. It is either a process that runs in the background or a procedure attached to a slot on a frame which can be executed any time the slot’s value changes. It has the advantages of allowing knowledge to be stored in modules.
In SAFETY FIRST, when changed methods are an integral part of the program, every time an object value is needed by the system and no value exists for it, a method associated to the object is fired to assemble a display to query the user. When changed methods are also used to provide information to the user as needed (e.g., user clicks a button asking for explanation, triggering an associated method). Many of the system's functions such as the unit conversion from English to metric are also implemented in the form of when changed methods.

8.3.2 Inference Engine

The inference engine or inference mechanism is responsible for the control and execution of the reasoning strategies used by an expert system. It is the part of the system that does the reasoning. The main goal of the engine is to be able to recognize that a fact in the knowledge base matches a condition in the real world, and lead the system reasoning (i.e., get more information about the real world or produce a conclusion, if any). This reasoning is goal-directed in some way and therefore computations within an inference engine relies on proving goals [Parsaye and Chignell 1988]. Among the reasoning strategies most used in expert systems are the backward and forward chaining schemes.

The backward chaining inference method (sometimes called goal-directed, top-down, or consequent-driven reasoning) starts with a specific fact or hypothesis (goal) to prove and works its way to all the facts or actions that can lead to that goal’s occurrence. The system operates from the assumption that the THEN portion of a rule contains the
goals to be achieved. Once a rule is chosen, the system goes to the IF section and finds the condition(s) that may lead to the goal.

Also known as data-driven, bottom-up, or antecedent-driven; the forward chaining inference scheme can be thought of as the opposite to backward chaining since it focuses in the IF side of rules rather than their conclusions. In general, this reasoning method goes forward from the facts (on the antecedent or IF side of the rule) to the conclusions they generate along the way. The conversion from fault trees to decision trees has made it easier for us to employ the forward chaining process in developing the knowledge base of SAFETY FIRST. This is especially true since we programmed the knowledge starting from the facts up to the conclusions.

The inference engine interfaces with the user through the user interface in order to get information about the conditions in the construction site at the time of the accident. Next, the inference engine matches these facts with the facts stored in the system’s knowledge base. Depending on the type of consultation, the system may fire all the rules that match the IF conditions, or may fire only one rule. For example, for the evaluation of the fall safety system adequacy, the system has to check all of the factors used to determine the system’s fitness for use. Therefore, the system will fire all the rules that match the antecedent side of the rule. In contrast, for the investigation of the causes of a fall the system will go through the causes sequentially as designed. As soon as the system identifies a problem according to the user input then it fires the rule that applies. If only one rule will be fired by the system at a given time, the system has been set up to fire the more complex rules first (i.e., according to the number of items on the IF side of the rule).
Further, if two rules with the same complexity can be fired, the first rule inputted will have a higher priority.

The inference engine also interacts with the external files interface in order to determine what text, graphics, or multimedia files need to be presented in each display. The file selection depends on the facts being asked from the user at the given display. In addition, the engine allows the user to access the help command from any place in the system.

8.3.3 User Interface

In order to reach a conclusion, the expert system needs to know the existent conditions in the construction site. This is the main task of the user interface mechanism: prompting the user for the information required to solve a problem. In addition to this task, the displays in the system should be designed so as to provide as much help on how to use the system, definitions and information about the terms used in the system, and explanations regarding why a given question is asked or information is required from the user. Furthermore, once a conclusion is reached the system should explain the reasoning behind the conclusion obtained, and present recommendations on how to avoid future fall occurrences.

To perform all of these functions, the user interface component has to be able to interact with all the other modules of the system and with the user. The user interface module interfaces with the inference engine and the knowledge base to determine what information should be required from and provided to the user of the system. It also
interfaces with external files to provide a more user-friendly system, including help statements and multimedia capabilities. All messages included within the displays are read from text files outside the system. The conclusions and recommendations are also stored in text files which are retrieved as needed. The inference engine determines which of these files should be called depending on the information provided or requested by the system's user. In addition, all inputs provided by the user are stored in outside files which are available for the user to recall in order to check his or her inputs during the consultation.

Furthermore, the expert system interfaces with the user through the different consultation screens in the program. Given that these displays are the first point of reference the user has to evaluate the program, a great deal of care has been taken in their design. The display should be aesthetically pleasing and user-friendly while performing its functions efficiently. Further, the displays should provide the users with the adequate information they may require without overwhelming them. In addition, the displays operation and components should be clear to the user; therefore, we have made the components and regions in all displays as standard and predictable as possible so that the user knows where to look for every component or utility he or she needs at any time in a consultation.

8.3.3.1 Moving Around The System

SAFETY FIRST is designed to lead the user to a conclusion by asking questions regarding the conditions in the construction site and evidence obtained from eyewitness of the accident. The user provides the information requested by the system through its
displays. Once he or she has done that, a forward (►) button is provided to allow the user to move forward in the consultation. The user must answer all questions given on the display in order for the button to be active and allow him or her to continue. The color of the label (►) in an active button is dark blue while the color in an inactive or blocked button is dark gray. If the user attempts to go on with the consultation while the button is blocked a beep sound will warn him or her of that fact and an explanation will appear in the display. A backward (◄) button is also provided on each display to permit the user to go back to previous displays and change any of the previously furnished information.

In addition, all displays in the system contain an Exit to end the consultation at any time and a Re-star button to begin a new consultation. Once the user selects either of these buttons, the user will get a message to confirm the command. If the answer is yes, then the system will ask the user if he or she wants to save the consultation (yes or no). Once an answer has been provided by the user, the system will execute the command.

All consultation displays also have a WHY IS THIS INFORMATION ASKED button which allows the user to query the program as to the significance of the current question to the final conclusion.

There are also some specific buttons included in some selected displays whose objective is to make the system more user-friendly. For example, the welcome display contains a “How to use SAFETY FIRST” button which allows a first-time user to go directly to the Help screen and learn how to move around in the system. Two more examples are the “Recommendations” button located in the conclusion display and the “Fall Safety Training” button located in the recommendations display. Both are included
to make it easier for the user to identify the more obvious options available to him or her at that given time in the consultation.

In order to move around the program the user may also take advantage of the menu bar commands located on the top of the display. These commands are discussed later in this section.

8.3.3.2 User Interface Structure

The general display structure of SAFETY FIRST starts with a welcome display which provides the user with the option of getting information about how to use the system. Next, the system provides an introductory display which informs the user about the system’s limitations and the information required in order to use the system. After that, the user will be asked to select the type of consultation he or she wants to perform (i.e., investigation, evaluation, design and planning, or training). If one of the experts system modules is selected, the system goes through a set of displays where the user may or may not input preliminary information about the investigator who gathered the information used in the system, the company under whose responsibility was the construction site being investigated, the site location, information about the worker who suffered the fall accident (if performing a fall accident investigation), and determination about the type of fall and structure component being analyzed.

After the above displays, depending on the consultation’s objective, the system will start the consultation to go through as many displays as required for the system to complete its objective (e.g., assess the cause of a fall accident). Once the consultation is
done, the system will provide a conclusion indicating the results of the evaluation (i.e., problems identified, if any), and recommendations to improve the site conditions. Finally, the user has the option to go to the tutorial program to get more information about fall safety topics (Figure 8.3).

8.3.3.3 The Displays

From this structure, we recognize that there are two main types of displays in the system: those that are part of the inference process of gathering evidence on the basis of which a conclusion is reached and those without which a conclusion could still be reached by the system.

8.3.3.3.1 Utility Displays

The utility displays are the ones which contain information that has no direct bearing on the system’s conclusion. The main function of these displays is to provide the user with information about the system, gather general information, or display the results.
of the consultation. Within this display category, the following displays are included: the welcome display, the introduction display, the preliminary information displays, the preliminary and final conclusion displays, and the recommendation displays.

The welcome display (Figure 8.4) is the first display the user encounters when entering SAFETY FIRST, its main objective is to provide the user with a chance to get some information about the system before going on further. He or she can do that by clicking the “How to use SAFETY FIRST” button. From this display, the user can choose to go on with the consultation (go to Introduction display) or exit the system.

The introduction display (Figure 8.5) has the function of informing the user of the scope and limitations of SAFETY FIRST and the cases in which it can be used. It also informs the user about the information he or she will need in order to successfully use the system. This information is provided before the user starts the consultation so that if he or she does not have it, he or she can exit the system and get the required information before starting the consultation. From this display, the user can move to the preliminary information displays, exit, or move back to the welcome display.

The preliminary displays (Figures 8.6 and 8.7) allow the user to select the type of consultation to be run, and input general information such as the name and title of the investigator and the name and address of the company in charge of the construction site being investigated. They also allow the user to input some relevant information about the fall accident (if a fall accident investigation is the objective of the consultation), such as the location of the site where the fall accident occurred, the name of the worker who fell, and so on. After these displays, the program will start the consultation.
As shown in the previous section (user interface structure), during a consultation the system will query the user about the site conditions, and provide preliminary and final conclusions that provide the user with the consultation results and an explanation of why these results have been obtained.

8.3.3.3.2 Consultation Displays

The consultation displays include all of the displays used to request from the user information essential to reach a conclusion. The order in which these displays appear during the consultation is determined by the system’s inference engine according to the knowledge base structure.

These displays have been designed to be as standard as possible so that once the user is familiar with the display’s structure, he or she will know where in the display he or she is expected to provide information, where he can get information, and where he can find the functions that allow him or her to go on with the consultation. In general, the consultation displays consist of six specific modules located in different places within the display, as follows:

1. The menu bar located at the top section of the display. This bar is standard for all the displays and will be described in detail in the next section.

2. The message on the top center of the display which identifies the structure component being investigated (e.g., Floor Edge Fall) and the type of component or problem is being investigated in the current display.
3. The main body located at the center of the display. It contains the questions the user has to answer in order for the system to reach a conclusion (e.g., determine the problems or causes of fall in the site). It also contains the possible input options the user has for the given question. For these inputs we take advantage of LEVEL-5 Graphics User Interface (GUI) which provides input mechanisms, such as radio-buttons, and check-boxes where the user only has to point to the right answer and click to select it. This area also contains a graphic illustration on the component being investigated.

4. On the bottom of the display, there is an area with five push-buttons which identify the potential options the user has within the current display (e.g., exit, restart, why is the current information asked, and backward and forward buttons). Finally, on the same area, whenever the user attempts to continue without providing the required input the system will provide a pop up window to provide instructions to the user of the system.

8.3.3.4 Input Mechanisms

Given that we decided to use a question and answer format to obtain the information from the users, the Graphic User Interface (GUI) input mechanisms were deemed to be the best for the user to provide answers to the systems questions. By using these input devices the user only has to point the mouse to the right answer and select it by clicking the mouse on it. SAFETY FIRST provides three main types of GUI input mechanisms:
1. Radio buttons (Figure 8.8) are provided if only one possible answer applies to the given question.

2. Check boxes are used if more than one of the options provided may be the answer to the given question. In a check box the user may choose as many options as they apply; however, the system may put some limitations on the inputs if the selected answers are conflicting with each other or previous answers.

3. Scroll buttons (Figure 8.10) are used when the user has to modify any of the numerical default values provided by the system, such as the posts spacing for the guardrail system.

Whenever too many answers may apply to a given question, the developer does not have enough information to predict the possible answers, or the system needs additional refinements to a given answer, the system provides prompt boxes (Figure 8.7) in which the user has to type information in response to a given question.

8.3.3.5 The Menu Bar

The menu bar is located at the top of all the displays in the system and contains all the commands required to operate the program. The commands used in the system are generally consistent with other windows commands. In some cases, specific commands were made clear enough so as to give the user an idea of their functions. The menu bar consists of the following commands: File, Units, Summary, and Help.

The File option contains the commands related to the operation of a system consultation file, such as New to start a new consultation in the system, Open to open a
previous consultation file, *Save as* to save a consultation, *Print screen* to print a display within a consultation, and *Exit* to end a consultation.

The Units menu option is only active on those displays where the user is asked to provide some numerical input. With this option, the user can specify whether he or she wants to provide these numerical inputs in *English* or *SI* units.

Finally, the Help command contains three items: *Help Contents*, *Acknowledgments*, and *About SAFETY FIRST*. The Help Contents command contains instructions on how to use help and how to operate SAFETY FIRST, background information about SAFETY FIRST, and a glossary of technical terms used in the system. The Acknowledgment command thanks the project sponsors and people involved on the system's development. Finally, the About SAFETY FIRST command provides information regarding the system developers.

**8.3.4 External Files Interface and External Files**

Finally, through the external files interface facilities allows the system to read the external files needed during a consultation. The inference engine determines which of these files should be called depending on the information provided or requested by the system's user. At this point, the system uses three types of external files: help files, text files, and bitmap files.

The SAFETY FIRST system uses the windows help compiler to provide users with clear and friendly explanation facilities (the structure of the SAFETY FIRST help file is discussed in Chapter 5). In addition, the system retrieves text files containing the
comments used in the displays, and the conclusions and recommendations. Furthermore, all of the inputs within a consultation are stored within text files outside the program; these files are used when the program has to jump from one module to the next or when the user chooses to save a consultation for later reference. All the graphics used inside the program are stored in bitmap files outside the program and are called by the program as they are needed. The system also uses audio (e.g., a beeper sound when the user tries to continue a consultation without answering the question in the display) and video files stored outside the program and called by it as they are needed.

Figure 8.4: Welcome Display
Introduction to SAFETY FIRST

The primary objectives of SAFETY FIRST, an expert system designed for etologic purposes, are to investigate the causes of construction fall accidents after they have already occurred and to determine the "weak links" or problem areas (as they relate to fall safety) in a construction project.

SAFETY FIRST can also be used for intervention purposes as a tool to avoid falls in construction. Note that for this purpose, the system bases its recommendation primarily on OSHA standards. Like any other standards, it concludes the minimum requirements to avoid such accidents, hence, if necessary, users may wish to implement more conservative measures when using the system as an intervention tool.

This system will ask the user several questions regarding the conditions at the construction site and, based on his/her answers, reach a conclusion. Therefore, in order to take full advantage of this system, the user should be familiar with the conditions in the job site being investigated or analyzed.

The SAFETY FIRST system has been designed to be as user-friendly as possible. However, there are some special commands and procedures involved. To learn how to use this system, please...
User Information

[Image of a user information form]

Fall Accident Information

[Diagram of a form with options for type of fall and elevated component]

Figure 8.7: Preliminary Display II

Figure 8.8: Fall Accident Selection Display
Is there any evidence that the collapse of the floor structure was the main cause of the fall?

- Yes
- No

Figure 8.9: Evaluation Display

For the guardrail system installed, what is the height of the top rail component?

Top Rail Elevation (in)

/ 42 \

TR Height = 42 in.

Figure 8.10: Evaluation Display II
CHAPTER 9

TESTING AND EVALUATION OF THE EXPERT SYSTEM MODULES

9.1 Introduction

Usually, developing a good expert system is a continuous iterative process and the program developed has to be updated or upgraded several times. In order to ensure that SAFETY FIRST can be used for its intended purposes, evaluation and testing by experts and users was conducted at all stages of its development. The knowledge engineers tested and evaluated the system at several stages of development to detect weaknesses in the system, such as features that did not perform their intended function, unclear instructions, conditions that were not previously considered by the system, and additional features required as suggested by the experts. This continuous evaluation has made major modifications less likely, particularly at the later stages of the development process.

9.2 Evaluation and Testing

The evaluation and testing of SAFETY FIRST was performed in three stages: first, during the preliminary stages of development, the knowledge engineers had to determine whether the expert system technology was the most adequate to use to handle the given problem as supposed to other more traditional programming languages. This first test is done to ensure the applicability of the system. Since the knowledge required for
SAFETY FIRST is mostly heuristic (based on experts knowledge of the world: rules of thumb, previous experiences), earlier evaluation revealed that it is best handled by an expert system. This conclusion is also supported by the fact that we concentrated on a specific domain area with specific boundaries (scope and limitations); where the significant knowledge required for the system development could be acquired.

In the second stage, the knowledge acquired for the system development was checked by the knowledge engineers and participating experts. At this stage, the knowledge structures developed to represent the knowledge were also checked to determine whether or not they represent the experts’ knowledge (i.e., this evaluation process was performed during the knowledge acquisition stage described in Chapter 5).

As for the expert system itself, the early stages of its development were spent in developing the knowledge base. At these stages, the system was checked informally but continuously by the knowledge engineers and participating experts to determine whether the knowledge base structure reflects the knowledge structures previously developed. In addition, all rules were checked to ensure that no errors were made while inputting the knowledge (i.e., facts and rules) into the system’s knowledge base.

Later, in the middle and later stages of the system development and once a defined structure for the user interface was developed, a formal evaluation sheet was created for evaluating and testing the system (the evaluation sheet and its parts will be discussed in the next section). The evaluation was performed by both participating experts, whose knowledge was represented in SAFETY FIRST, and independent experts, whose knowledge was not represented in the system.
9.3 Formal Evaluation and Testing

Throughout its development, the system was continuously checked by both the knowledge engineers and experts to guarantee its usefulness and the accuracy of the system's logic and conclusions. In addition, from the middle to later stages, the system was also evaluated by independent experts and potential users. To perform this evaluation, a system evaluation form was developed (Figure 9.1) The system was evaluated in terms of the conclusions accuracy and completeness and other system's characteristics, such as the user interface (ease of use), the system's questions during a consultation (clarity of questions), the system's efficiency (capability and efficacy of the consultation scheme, including ), the system's applicability (the practicability and potential usefulness of the system in the field), and finally, the system's overall performance (overall impression of the system).

Five expressions were provided for the evaluation of each of the above ratings: 
*very good*, *good*, *fair*, *poor*, and *very poor*. The following are the guidelines given to the user as to how to use the rating:

- *Very good*: little or no improvement is required
- *Good*: some improvement is required but no major mistakes are detected.
- *Fair*: some problems are detected but performance is satisfactory.
- *Poor*: major changes are required.
- *Very poor*: redevelopment is required.
The system was tested at several stages of its development. At each step, the evaluator's comments were collected, evaluated, and incorporated into the system if deemed adequate. The summary of results from the final evaluation is presented next.

**SAFETY FIRST EVALUATION FORM**

Evaluator: ..............................................................
Affiliation: ............................................................
Position: .................................................................

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequacy</td>
<td></td>
</tr>
<tr>
<td>Explanation</td>
<td></td>
</tr>
</tbody>
</table>

**Conclusions by SAFETY FIRST**

Adequacy: Conclusions given by the system are adequate.
Explanation: Adequacy of explanations within the conclusion.

**System's Performance**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Interface</td>
<td></td>
</tr>
<tr>
<td>Questions</td>
<td></td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
</tr>
<tr>
<td>Applicability</td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td></td>
</tr>
</tbody>
</table>

User Interface: User friendliness of system environment, including on-line help.
Questions: Clarity of questions and data required during the consultations.
Efficiency: Efficiency and ease to use consultation scheme.
Applicability: Usefulness and practicality of the system.

Figure 9.1 System Evaluation Form

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9.4. Evaluation Results

Several groups of experts and users have evaluated SAFETY FIRST. The results of their evaluation and testing of the program have been included throughout the development of the system. Their contributions have considerably enhanced the performance of SAFETY FIRST. In this section, a discussion of two formal evaluations of the SAFETY FIRST expert system modules is presented.

The first formal testing and evaluation took place on November 1995. During this test, a representative subsystem of the SAFETY FIRST investigation expert system (i.e., floor edge component) was evaluated by nine experts/users consisting of two experts from the Bureau of Workers Compensation (BWC), two safety consultants, two persons in charge of safety programs for the Builders eXchange (BX) of Columbus, and three potential users from different construction companies with jobs at different management levels.

The results are presented in both bar charts and pie charts. The bar charts show the number of people assessing the system for a given rating. The pie charts indicates the percentage of answers for each rating. Two-thirds of the evaluators felt that the conclusions provided by the system were adequate and had the right amount of explanations (Figures 9.2 and 9.3). Two evaluators considered the conclusions as very good and one them of evaluated the conclusions as fair.
Next, most evaluators thought that the user interface is more than adequate. Six of them rated it as very good (Figure 9.4). The questions by the system are also rated high (between very good and good) in terms of their clarity (Figure 9.5). Furthermore, the efficiency of the system was judged to be better than good with seven of the nine evaluators rating it as good and the other two rating it as very good (Figure 9.6). As for the system’s applicability, the evaluators also considered it as better than good (Figure 9.7). Some of the evaluators commented that the system was good for post accident
investigation (diagnosis), but could be improved for prognosis. They indicated that the system would be more widely used if the site evaluation module was a stand alone module incorporating more details. Finally, Figure 9.8 shows that most of the evaluators rated the system’s overall performance as good or better than good (about 90% of population).

Figure 9.4 System’s User Interface (Question 3)

Figure 9.5 Questions in the System (Question 4)
The second formal testing took place on April 1998. During this test, the evaluators were asked to evaluate at least one branch of the three expert system modules of the SAFETY FIRST program. The system was tested by six expert/users, including one
expert from the Bureau of Workers Compensation (BWC), two safety consultants, one person in charge of safety programs for the Builders eXchange (BX) of Columbus, and three potential users from different construction companies with jobs at different management levels.

The results of the evaluation are presented in both bar charts and pie charts (Figures 9.9 to 9.15). From comparing the results from this evaluation with those from the previous one, it can be observed a marked improvement in the program. The conclusions (Figures 9.9 and 9.10) in the new evaluation were evaluated as better than good. The questions given by the system were ranked between good and very good (i.e., three evaluators rated them as being good and three rated them very good). All evaluators found the user interface of the system to be very good. The systems efficiency and applicability were ranked good by sixty seven percent of the evaluators and very good by the remaining evaluators. Finally, the system's overall performance (Figure 9.15) was rated very good by five of the six evaluators. The remaining evaluator rated it as good.

The following are some of the general comments the evaluators gave about the system and its performance during the two formal evaluations:

"I tried several times to fool the system into giving me an incorrect answer and it never did. It correctly picked up the information from the answers to the questions I gave."

"This is a good system for post-accident investigation. As a training tool, this program would greatly aid in hazard recognition for novices and allow
determinations to be made to insure the work site is free from fall hazards that the workers will be exposed to.”

The evaluators also indicated that the system’s performance was improved compared to previous validations. The following are some of the comments in this regard:

“‘A definite improvement. Several reasons: 1) scenarios were more broad, 2) conclusions were more in depth. I felt the addition of the code information made a big difference on my confidence on the final conclusion.’”

“You have done a great job of correcting some problems from our first review....

First, here is what I really like:

- Cross checking to OSHA code numbers
- Expanded info in conclusions to address ‘don’t know’ answers
- The Stop signs to explain that your choices contradict each other
- Having more scenarios and options covered”

“The changes made have:

- increased the speed of the operation
- the “don’t know” option helps pinpoint areas that need to be checked [further] on site
- it asks pertinent questions”

Finally, some of the evaluators expressed that they believe that currently the expert systems for investigation of falls and evaluation of fall safety would be a more useful tool
for the construction industry. They expressed concerns regarding the potential use of the
design and planning expert system. They argued that designers are not eager to assume
part of the burden for safety. A burden currently born solely by construction contractors.
However, they acknowledged this tool could be potentially useful in the future.

Some of these comments have been used to improve the expert system modules of
the SAFETY FIRST program. If the comments, though important, could not be
incorporated within the current program (e.g., they were beyond the scope of this study),
they were included in the recommendations for future studies.

Figure 9.9: System’s Conclusion’s Adequacy

Figure 9.10: System’s Conclusion Explanation
Figure 9.11: System's User Interface

Figure 9.12: Questions in the System

Figure 9.13: System's Efficiency

Figure 9.14: System's Applicability
Figure 9.15: System’s Overall Performance
10.1 Introduction

In general terms, training may be defined as helping people (trainees) to acquire both the declarative and procedural knowledge required to perform a job properly. Declarative knowledge includes general knowledge about the training’s subject matter, such as definitions, factual information, and procedures and the reasons behind their existence. Procedural knowledge includes more domain specific knowledge, which through constant use becomes automated. Examples of this kind of knowledge are perceptual skills (i.e., attitudes and ability to detect or identify certain situations), strategies which allow the trainee to react to particular situations, and psychomotor skills [Gordon 1994].

Training is usually used for three main situations [Gordon 1994]:

1. For new recruits (i.e., employees) who do not have the background knowledge or experience required by the job. Trainees need to learn specific procedures, factual information, and skills required to perform the job efficiently. Under this group is the case in which a completely new (i.e., innovative) method or procedure is to be used for a job and therefore workers need training regarding it.
2. For employees in the company who are changing work. They are familiar with the construction work environment, but lack the key safety training on the new environment and the job hazards he or she will be exposed to.

3. For current employees whose performance of certain tasks is not up to the levels desired by the employer. In this case, the training will attempt to overcome the workers' shortcomings and strengthen the workers' positive skills or traits, the final objective being to fine tune their performance.

The focus of the training can be on three areas:

1. Areas in which new skills or improvement may be desirable. For example, areas where worker accidents have been partially caused by the worker's lack of familiarity with the environment and its hazards, and where training may be used to increase the worker's knowledge about the hazards and the safety procedures to control them.

2. Areas in which the skills or improvements are required by the job performed. For example, in fall protection, the use of control access zones requires the worker to be trained in fall hazards and how to react to them. This system relies on the worker's ability to behave safely, recognize hazards and react to them; there are no physical devices (i.e., barriers) protecting the worker from falling.

3. Areas where system or equipment changes render previous training obsolete (e.g., starting on January 1, 1998 the use of safety belts for fall arrest systems was outlawed).

In order to be successful, a training program must consider its audience's education and skill level. The training program should be the best way to both address the
performance problem in the job site and impart the type of knowledge required by the job tasks. Further, in order to gain the worker's trust, the contents of the training program must be comprehensive (i.e., important materials are not omitted) and without errors (i.e., it does not provide erroneous information). In addition, the training program must have the support of the senior management both for its budget allocation and implementation. Research indicates that the efficiency of the training will increase if the contractor has a safety program which reinforces the training knowledge in the field. Finally, the training program must be flexible. It should be able to change according to new needs in the field. It should also allow the developer to improve it as data from the field identifies weak points in the program's knowledge. Figure 10.1 shows the phases which can be used for a systematic development of any training system.

![Figure 10.1: Training system development cycle [Pont 1996, Gordon 1994]](image)

The use of training must be justified as the best way to address the problem at hand (i.e., needs assessment). For example, a construction safety problem may be
addressed by changing to safer construction methods. Therefore, the current and expected job conditions must be analyzed to determine whether the training is the best feasible way to address the problem. Once this is done, during the system planning and design stage, the desired outcomes (i.e., objectives) of the training must be defined in specific terms. Further, the topics and knowledge required to reach the objective must be specified. The order in which each piece of knowledge should be presented and the emphasis to be placed on it should be determined. The worker attitudes towards that knowledge and their applicability under job-specific situations must also be studied. Finally, given the knowledge requirements, the developer must choose the instructional methods to be used to deliver the training system. The delivery strategy to be used for the system will be chosen based upon the delivery system selected.

The next stage (i.e., development) involves the organization of the course lessons and course structure (i.e., sequencing), development of prototypes, and development of the full scale system. Finally, the system will be delivered and its completeness and efficiency evaluated. As shown in Figure 1, in addition to the final evaluation, throughout every stage of its development, the system goes through a series of formative testing that helps shape the final form of the system. Further, at any stage, the developer may go back to previous stages and change the system as needed as a result of the feedback obtained from the trainees.
10.2 Training Knowledge Requirements

A major application of training in construction is on the safety area, where major strides are yet to be made on reducing worker's fatality and injury rates. "Effective training is a cornerstone and an essential element of any environmental safety and health program" [ReVelle and Stephenson 1995]. Training is used to complement the safety methods already designed to prevent accidents or as a last resort to warn workers and teach them procedures to protect themselves. In the first case, training teaches workers what type of job related hazards exist and the devices that are going to be used to scale down their significance (i.e., fall protection devices, warning signs, etc.). The second case occurs when an engineer is not able to reduce the hazards through design or safety guards. For example, the use of control access zones (CAZ) where the fall hazards are not eliminated but restricted to a few trained workers who have access and must work on it.

Another objective of training is to change worker and management attitudes regarding safety and its significance. Spigener describes the importance of training as follows:

"Training may be more crucial to success in safety than in either quality or productivity ... When it comes to occupational safety, the human learning cycle is plagued by a paradox that sets people up for injury. That paradox is this: individual experience does not match group risk ... That means that even in the case of a critical at-risk behavior, an individual may perform it a thousand times with no ill effect--the outcome is unpredictable. However, when hundreds of workers each perform that at-risk behavior thousands of times, there is no
unpredictability about the outcome—someone is going to get hurt” [Spigener 1995].

According to Spigener, the employees’ behavior will not change unless their beliefs and experience changes. By using employee driven safety, the experience of all individuals in the construction team is pooled and used to monitor the behavior of individuals as a group. Therefore, instead of thinking injuries are rare events, the group focuses on the certainty that something is going to happen unless they develop new habits.

The final objective of training is to empower workers and managers to recognize safety problems and react to them. The focus of the safety shifting from OSHA code compliance (i.e., comply with minimum requirements or behave safely only while OSHA inspectors are on the site) to creating a construction site where no safety incident is acceptable.

The role of training should be well defined in the construction company’s safety goals, policies, and procedures. Training programs by the company should fulfill the role of educating both managers and workers as to the hazards they are exposed to, the procedures implemented to control them, the reasons behind these procedures, and the impact of each party (i.e., workers and managers) on the success of the safety program.

Therefore, the training program should be able to educate workers and managers regarding site hazards, unsafe and safe procedures, safety cautions, and other vital information related to the subject (i.e., declarative knowledge). In addition, workers and managers must be able to perceive dangerous situations and have the skills to react properly to them (i.e., procedural knowledge). Both the background knowledge (i.e.,
why) and the skills knowledge (i.e., how) are significant to educate workers and encourage them to change their safety practices for the better (i.e., reduce the number of unsafe behavior instances).

10.3 Training and Its Role in Construction Safety

The construction industry faces certain conditions and problems that set it apart from other industries in terms of safety [King and Hudson 1985]:

1. The temporary duration of work sites combined with the rapidly changing nature of the work and hazards associated with it. Given that the job and its hazards are continuously changing safety precautions need to be updated continuously. So, they should be controlled by someone in the site. Further, different job sites imply different hazards to be recognized and overcome. Therefore, for a period of time, all workers are new to the working environment.

2. The seasonal employment. As a result of weather conditions, a great amount of the construction work takes place at certain seasons favorable to construction work (e.g., summer). This may lead to a constant change of labor which on slow work seasons may move to other regions or more stable jobs in other industries.

3. The small size of construction firms. “They cannot afford the services of safety specialists or instructors, so that there is little opportunity for organized safety instruction, whether on or off the job ... Many small firms are short of capital and under greater pressure than larger ones to cut costs at the expense of safety” [King and Hudson 1985]. Further, it is more difficult for OSHA inspectors to monitor the
work and practices of a large number of small firms than to monitor a smaller number of medium to large sized firms.

4. The extensive use of subcontractors in the industry. This causes problems of coordination, planning, and allocation of safety responsibilities.

5. The high labor turnover rate. This is caused by the temporary nature of construction and the season effect which causes workers to move from site to site. "A high labor turnover in any job is not conductive to a good safety and health record. It also leads to workers leaving a job before they are properly conversant with most of its details, including safety, while the employer is constantly faced with the need to train new workers" [King and Hudson 1985].

All of these conditions have contributed to the high injury and fatality rates existing in construction, especially because they lead to a high number of new workers at all stages of construction projects. Levitt and Samelson [1993] note that "New workers are especially vulnerable to accidents ... Workers who have been on the job for less time account for 25 percent of all construction accidents ... Therefore, it is possible to obtain a dramatic reduction in accidents by simply reducing the risk of injuries to the most vulnerable sector of the construction work force--new workers. Note that 'new workers' in this context means any workers who are new to a project, no matter how old or experienced they might be."

One of the ways that can be used to try to curb down injuries and death of workers in the industry is to provide safety training for workers. Currently, OSHA standards require contractors to provide training to workers exposed to certain hazards, such as
falls. They also require contractors to keep records signed by the worker indicating that they have been given the training required under the ‘right-to-know’ act. Further, in some states (e.g., California), OSHA standards require contractors to perform on site safety toolbox meetings at least once every ten days.

The problem with these regulations is that they do not guarantee that the worker is learning from these ‘training’ sessions. Although, according to the standards, employers should monitor their workers and ensure their skills and knowledge are adequate. Unfortunately, in most cases, these training sessions are one sided (i.e., lecturer or video presents the information which the worker may or may not grasp) and geared towards the fulfillment of the employer’s legal obligations, as opposed to teaching workers how to behave safely. Frequently, the main objective of the contractor is to spend as little time and money on these sessions, giving workers the idea that safety is disposable if the right circumstances occur. Therefore, the result is the trivialization of the regulations whose final objective is ignored.

The most commonly used methods of training in the industry are: video safety courses, yearly or bi-annual lectures, on the job training, and toolbox safety meetings. Video courses are very popular given their timeliness in terms of availability. Every time a new worker comes to the company, he or she is asked to watch a ‘training’ video and then to sign a release form indicating he or she has been instructed about safety. The main problem with this system is the lack of involvement on the part of the worker, who in most cases cannot clear his or her doubts about the video. Further, the worker’s comprehension of the topic is rarely tested.
Lectures are more effective in terms of imparting knowledge, though the time span available for such courses is limited. Therefore, the training knowledge must be delivered at an accelerated pace, making the trainee’s learning level still questionable. Further, lectures cannot be set up for every worker that arrives in the company due to cost and instructor availability problems.

Toolbox safety meetings are weekly or by-weekly meetings held on the job site to discuss safety topics or problems which may be encountered by workers during upcoming work operations. This requires planning on the superintendent and foreman to decide which safety topics should be discussed during the meeting. They should provide a channel for managers and workers to openly discuss potential safety problems (i.e., get workers input). Unfortunately, in many cases, these meetings are run in order to fulfill the contractor’s legal obligations. Therefore, they end up becoming a five minute coffee drinking break where workers are given a handout about certain irrelevant topics (e.g., fall protection from higher elevation while driving steel piles) and then asked to sign an attendance sheet for record keeping purposes (i.e., in case of OSHA inspection).

Finally, on-the-job training or apprenticeship (for union workers) is an effective way to teach the workers the skills they require to function on the job site. Unfortunately, many workers do not have the time or inclination to mentor or monitor a novice worker. The major problem with this method is that novice workers are still exposed to the site safety hazards while learning their trade. A safer approach would train novice workers on the expected hazards before they would be exposed to them.
There are indications that OSHA is concerned with the trivialization of the standards and is trying to improve the codes. For example, Tennessee recently adopted the Federal Hazard communication Standard but added the following key clarification to the section on employee information and training: "Training required by this law shall ensure that employees who may be functionally illiterate or who have problems reading and understanding English are appropriately informed and trained in accordance with this rule. The effectiveness of training shall be measured by adequacy of reasonable basic and simple verbal recall by the employee of information required by this rule. During the course of inspections or investigations, compliance officers shall evaluate training through employee interviews" [Baldwin 1991]. Therefore, OSHA inspectors have the right to test the worker hazard awareness by means of interviews, or behavior observation. Under this system, compliance is assessed on the basis of the quality of teachings, rather than the presence of a sheet signed by workers indicating their attendance to certain safety meetings or to watch certain safety movies.

10.4 Fall Protection Knowledge and Training

The new OSHA standards for fall protection require the employer to provide training (CFR 1926.503) for each employee who might be exposed to fall hazards. The training should enable each employee to recognize the hazards of falling and train each employee in the procedures to be followed in order to minimize these hazards. OSHA recommends that employees should be trained in the following areas:

1. the nature of fall hazards in the work area,
2. the correct procedures for erecting, maintaining, disassembling, and inspecting the fall protection systems to be used,

3. the use and operation of guardrail systems, personal fall arrest systems, safety net systems, warning line systems, safety monitoring systems, controlled access zones, and other protection to be used,

4. the role of each employee in the safety monitoring system when this system is used,

5. the limitations on the use of mechanical equipment during the performance of work on low-sloped roofs,

6. the correct procedures for the handling and storage of equipment and materials and the erection of overhead protection, and

7. the role of employees in fall protection plans.

These items outline the minimal knowledge a worker exposed to fall protection hazards should know and therefore should be exposed to during a fall protection training course. However, they are by no means comprehensive. Other knowledge which may complement this knowledge, includes background information about other types of accidents in construction and the human (i.e., injuries or deaths) and material costs (e.g., workers’ compensation) related to them, the most common causes of fall accidents, and other methods of accident prevention (e.g., the use of design and planning reviews to eliminate hazards from the project’s outset, or the implementation of an effective safety program).

Further, OSHA standards do not limit the employer’s responsibility to providing the knowledge, they require the employer to verify that all of the knowledge above was
learned by the worker. Towards that end, OSHA requires the employer to prepare and keep on file a written certification record which should contain the following: the name or other identity of the employee trained, the date(s) of the training, and the signature of the person who conducted the training or the signature of the employer. If the employer relies on training conducted by another employer or completed prior to the effective date of this section, the certification record should indicate the date the employer determined the prior training was adequate rather than the date of actual training.

If the employer has reason to believe that a worker previously trained has not acquired the knowledge and skills mentioned above, the worker should be retrained. OSHA lists the following situations where retraining is needed:

1. changes in the workplace render previous training obsolete,
2. changes in the types of fall protection systems or equipment to be used render previous training obsolete (e.g., use of safety belts for fall protection used to be allowed under OSHA standards. Starting on January 1, 1998 their use was outlawed),
3. inadequacies in the use of fall protection systems or worker behavior which indicate that he or she has not retained the requisite understanding or skill.

As mentioned in the previous section, a major problem is that employers often provide the training as a way to fulfill their legal obligations. Therefore, they rarely follow up or evaluate the effectiveness of the training provided. It follows that retraining is rarely provided; even though, the situations mentioned before are often encountered.
10.5 Delivery Systems

Depending on the type of knowledge that must be delivered by the training system, the trainer has a choice of several instructional techniques to use. Each one of these techniques has positive and negative aspects which will make their use more or less desirable depending on the context in which they are to be used. Following is a summary of the most common instructional techniques and their strengths and weaknesses [Gordon 1994, Mitchell 1993]:

10.5.1 Text and electronic text.

This includes written text on both paper (i.e., hard copy) and computer but accessed in a book-like manner (i.e., electronic). They have the following strengths: (1) low development and delivery costs, (2) little or no training is required by users given that most of them can read, (3) trainees can use them at their own pace, and (4) they are always available for future reference.

The main weakness of these delivery systems is their lack of interactivity. They cannot adapt to their user’s knowledge and needs. They require reading and studying skills from the user and are more difficult to modify than other delivery systems.

10.5.2 Audiovisual techniques.

They include delivery programs which take advantage of visual media, such as TV and videotapes, and audio media such as cassettes and compact disks. Computer related media is not included here. The use of video training courses has been widely used in the
construction industry mainly because they are simple to deliver (i.e., use video player to play the course to the trainee) and are inexpensive compared to other training techniques. Ideally, trainees can learn and use them at their own pace by rewinding and playing the video tape back. Further, as with the previous device, the video is always available for future reference (though in this case a video player is needed). Finally, they take advantage of the worker's visual and auditory senses.

The development and delivery costs of these courses are higher than those for texts. They are not interactive. The communication is only one way from the training course to the user. The user cannot actively participate in the learning (e.g., he cannot ask questions). Finally, the course does not provide incorporated ways to test the user learning.

10.5.3 Lectures.

This is one of the most commonly used teaching methods. Under this method, a lecturer, who is usually an expert, gives a presentation on the subject matter to a group of trainees. This method has low development and delivery costs and is easy to modify both in the short and the long run. During a lecture, the lecturer can evaluate the knowledge level of the trainees and adapt it to them. Further, the lecture contents can also be modified and updated to keep up with changes in the subject. This method has the potential of being interactive, depending on the lecturer teaching skills (i.e., whether he or she can encourage student participation).
As for their weaknesses, lectures are costly to deliver given that both the instructor and the student must be at the same location (i.e., classroom). Lectures are usually not adaptable to the individual needs of students. Usually, they are aimed to certain knowledge level (e.g., average level or the slowest student in the class). This causes a problem for heterogeneous classes where different levels of knowledge exist. Advanced students get bored if the level of knowledge is under their own or slow students get left behind if the level of knowledge is above their own. Finally, lectures are usually one sided with the instructor having control over the contents and pace of instruction delivery.

10.5.4 Tutoring.

In this case, an instructor (i.e., tutor) and a trainee interact on a one-to-one basis. This relation between the instructor and the trainee makes it very effective to pass on both declarative and procedural knowledge. The teaching and contents can be adapted to the trainee’s knowledge level; as a consequence, the student is actively involved in learning. Finally, the student’s learning is tested and immediate feedback is provided by the tutor.

This method is costly both in terms of time and money. Compared to lectures which allow one instructor to teach several students, tutorials require one instructor to focus on one student. This makes it very effective to impart knowledge, but very expensive in terms of instructor time. Further, some students may be intimidated from having the tutor’s full attention and not respond well to the method. Finally, tutorials are more effective to impart declarative knowledge. They do not impart enough procedural knowledge.
10.5.5 Simulators.

These are "artificial recreations of some real world environment" [Gordon 1994]. The physical conditions of the real world are duplicated in a confined and safe environment where the trainee knowledge can be tested and improved. This method is ideal for teaching procedural knowledge (e.g., skills). The simulated environment allows the trainee to face dangerous situations he or she would face in the real world without endangering his or her life. Moreover, the high level of interactiveness of the environment (i.e., provides both audio and visual feedback), challenges and motivates the trainee to learn. Finally, because it is a computerized system, the trainee can practice as much as needed.

Simulators have high development costs which make their current use in the construction industry unlikely. Further, the simulation environment is difficult to modify to respond to different situations to those contemplated at design time. Finally, it does not teach enough declarative knowledge. Their main use is in teaching skills. Therefore, it should be combined with another method.

10.5.6 On-the-job training.

This is a procedure by which the trainee is taught by another worker or a supervisor what to do and how to do it. Usually, the trainee spends a period of time with an experienced worker, observing and learning from him or her. Its main advantage is that
is easy to implement and is not costly given that no special instructor or equipment is required. This is one of the best methods to teach procedural knowledge.

Its main weakness is that in most cases it is not systematically designed and implemented; therefore, the quality of teaching varies, depending on the trainer. Often, the trainer does not have enough time, basic knowledge, or communication skills to teach the new worker. Finally, it exposes the trainee to a dangerous work environment before he or she has received safety training about the expected job hazards.

10.5.7 Traditional programmed instruction.

This is based on the principles of behaviorist psychology theory, which states that "learning would be optimized if instructions allowed the learner to respond frequently and be immediately reinforced for a correct response" [Gordon 1994]. Therefore, programmed instruction teaches small amounts of information at a time (i.e., information presented in small steps) and then tests the user comprehension by giving a set of questions associated with the given information (i.e., immediate feedback). Computer programmed instruction (CPI) usually has two forms: linear or branching. The second one being a little more interactive in that the next bit of information to be presented to the trainee depends on his or her current answers. CPA has the advantage of being cheaper and easier to develop than other computer assisted instruction systems, while being easy to use and moderately interactive. It teaches declarative knowledge in small steps, allows the user to test his or her learning, and provides appropriate feedback.
CPA programs require large development costs (i.e., computer hardware and software, and the developers’ time and effort). Further, the user must have a minimal computer operation knowledge in order to run the program. Finally, CPA programs are not very interactive. They place the user in a passive role (i.e., read information and answer questions) and do not allow the user to explore other paths of knowledge.

10.5.8 Computer assisted instruction (CAI).

This term describes various computer based programs that use different methods to teach trainees. The instruction imitates in a computer media the interactions that may occur between a trainee and a lecturer or tutor. This term includes tutorial programs (CAI), whose focus is on developing an effective interface with the user (e.g., tutorials, computer simulations, database, and hypertext and hypermedia programs), and intelligent computer assisted Instruction (ICAI), programs which attempt to model the domain knowledge and the interactions between the tutor and the trainee (i.e., they can tutor, guide, test, and help the user as he or she explores the information to be learned). The following are the strengths associated with this delivery system:

- It is always available for use.
- It allows for the use of mixed instructional strategies.
- It can be highly interactive.
- It has the potential of adapting to the user knowledge level.
- It can include modules for testing the user knowledge level.
- It is effective to deliver both declarative and procedural knowledge.
• The training time may be shorter.

On the other hand, CAI has the following weaknesses:

• It requires computer hardware and knowledge from the user.
• It requires large development time and effort.
• It requires the developer to anticipate the user needs.
• The trainee can not practice and test certain skills (procedural knowledge) on a computer.
• The development and modeling of the knowledge required by ICAI systems is “extremely difficult and the technical capability to create such a system barely exists” [Gordon 1994].

The temporary nature of construction projects makes it unlikely for a worker to stay in a company over a long period; thus, workers are constantly coming in and out of the company and the industry. Therefore, the delivery of the training must be available at all times. The use of lectures and tutoring is not always available. The use of text books or video or audio courses is an option; however, their effectiveness in teaching workers is in question.

Given the high level of risk associated with construction operations, “it is imperative that the employee receive key safety and health training before being exposed to job hazards” [ReVelle and Stephenson 1995]. The seriousness of the hazards involved, makes the need for worker training an immediate priority. On-the-job training or coaching is a good way to teach the worker practical job skills; however, this training method exposes a novice and untrained worker to a hostile construction environment. This method
would be better applied once the worker has gone through a basic safety training that enables him or her the tools to recognize and deal with on-the-job hazards.

The use of simulators would be another way to train workers to recognize and deal with the hazards associated with a construction environment, while in a confined and safe environment. However, the hardware and development costs associated with the use of technique make its use unlikely.

Given the types of knowledge needed to train workers and managers to perform their jobs safely, many of the instructional techniques discussed above could be applied. However, “the best training programs are those that use a variety of methods to present the message” [LaBar 1993] and computer assisted instruction has the advantage of being able to apply a combination of strategies and media that make it best suitable to impart both declarative (i.e., factual information about falls and how to prevent them) and procedural knowledge (i.e., perceptual skills and automated strategies to detect and react to safety problems). Further, “The interactive format is particularly well-suited to deliver precise technical information [and] the self paced format reduces training time and increases comprehension of safety-critical activities.” [Kyle 1996]. Finally, CAI has the advantage of providing automatic record keeping capabilities so that worker training information (i.e., who was trained, in what job topic, on what date, and the participation and success rates of the trainee) is constantly available for review.
10.6 Delivery Strategy

As previously mentioned, computer assisted instruction can occur in many ways and using many different strategies. The most commonly used strategies to develop CAI are the following [Nadler 1984, Gordon 1994]:

1. Drill and practice. This method is not usually used to impart new knowledge. It is mainly used for skill practice to judge mastery of the subject. During a typical drill and practice consultation the computer will present the user with a problem or question, accept his or her response, judge the answer, give feedback to the user, and present a new question more or less challenging based on the previous response.

2. Tutorials. These can be used to teach both declarative and procedural knowledge. Typically, a consultation presents information at the outset and then by using quizzes or other means checks the trainee understanding of it.

3. Information access. This presents and gives the user full freedom to access and explore information on the subject matter. It consists of chunks of information (i.e., text or multimedia) stored in the computer or a peripheral (e.g., CD-ROM) which can be accessed through a graphic interface (e.g., hypertext or hypermedia) or a special program (i.e., database).

4. Simulation. This is a computer representation of some real environment. It allows the user to safely study the effects of his or her actions on the environment. Instructional games are a form of simulation which add a competitive element to the environment (e.g., time or score).
Each of these strategies has its strengths and weaknesses which make them more or less effective to deliver factual knowledge or perceptual or strategic knowledge. For example, tutorials and hypertext and hypermedia are a good media to deliver declarative knowledge; however, less effective for procedural knowledge. In contrast, simulations are better for teaching procedural knowledge and less effective for teaching facts and concepts.

10.7 The Training Program

Given the delivery strategies discussed above, Figure 10.2 displays the structure proposed for the training module of SAFETY FIRST. The program incorporates three strategies: tutorial, information access, and simulation. The combination of these strategies allows the system to deliver both the declarative and procedural knowledge required by its users (i.e., workers, novice engineers, and managers). The more basic knowledge required by all users is included in the main lessons of the program, while other topics that may be of more interest to managers (e.g., foremen, superintendents, and project managers) are included in the form of hyper-lessons which can be accessed at any time during a consultation.

As shown in Figure 10.2, at the start of the program, the user will have to choose the module he or she wants to use: training or information access. If the user chooses the training module he or she will go through a question and answer evaluation session to determine his or her knowledge level and use it as a base line to evaluate the user's progress. Next, the system will move the user into a display where the user will select the
lesson of interest in the tutorial. Each lesson includes one or more related topics for which both explanation and testing is provided. At any time during a lesson, the user may choose to explore related knowledge topics through the use of hyperlinks. Further, site simulations will be embedded within the explanation and the testing facilities, in order for the user to acquire skills, procedures or hazard recognition knowledge. If the user chooses the information access module, he or she will be able to access the stored training records of a given worker. These records are available in two forms a tabular form and a textual historical form. In the coming sections, each of these program components will be discussed in detail.

![Diagram of the SAFETY FIRST Training Program](image)

**Figure 10.2:** Structure of the SAFETY FIRST Training Program
10.7.1 The Welcome Display

This is the first display encountered by the user once he decides to run the SAFETY FIRST training program (Figure 10.3). In this display, the user will be able to choose the module of the program he or she wishes to access: training or record-keeping. If the user is a trainee, he will choose the training module. In the other hand, if the user is a member of management wanting to check on an employee’s training record, he will choose the record-keeping module.

10.7.2 The Training Module Access Display

This is the first display encountered by the user once he or she decides to run the training module of the program (Figure 10.4). In this display, the user (i.e., trainee) is asked to input some information about him/herself: name, ID number (e.g., social security number), and job title. The user will not be able to continue until this data has been provided. This data is used by the program in order to store the results of the user consultation. Further, this data can be saved and used for administrative purposes (i.e., to monitor the user progress). For example, to record the results of the user preliminary test and tests at the end of lessons in the tutorial.
Safety First Training - Control Panel

Select one of the two modules and then click the continue button.

The record keeping module can be used by management to monitor the employees' training progress (e.g., to check what lessons have been taken by certain employees).

The training module can be used by employees and managers to receive training in all aspects of fall protection.

Figure 10.3: Welcome Display

Further, this will also allow the user to complete some of the lessons in the tutorial and, at a later time, come back to the program and take the remaining lessons; without having to retake the preliminary test or the lessons already completed. The user will only have to enter the input information on the welcome display and his or her consultation record will be automatically recovered by the program.

If the training program is activated from the recommendation display of one of the expert system modules (i.e., investigation or evaluation) in SAFETY FIRST, the program will go directly to the lessons selection display. In this case, the program does not need to keep records about the user performance. Therefore, the user will not have to go through the welcome and preliminary test displays.
10.7.3 The Preliminary Test Component

In order to evaluate the knowledge level of the user before going through the training, the program gives a simple preliminary test regarding falls in construction. This test also acts as a base line, which combined with the results from the tutorial tests, allows the program to evaluate the worker progress. Before starting the test, the user is presented with an introduction to the test display explaining the objectives of the test and how to deal with the test questions (Figure 10.5). Next, the user takes the test which consists of ten questions, each one corresponding to one of the ten lesson topics in the tutorial segment of the program. Finally, the user is presented with the results of the test and a summary of the questions and their correct answers (Figure 10.7).
Before getting into the SAFETY FIRST tutorial, please take a small pre-test (20 questions) to see how familiar you are with the topic of fall safety in construction.

The test uses multiple choice questions. The questions are not tricky, however, please consider all the alternative answers carefully before continuing.

Once you are done with the test, you will be able to see the correct responses to all of the provided questions.

You will only have to take this test once. Next time you log in, you will be able to skip it and go on to the tutorial lessons.

Relax and take your time.

Figure 10.5: Preliminary Test Introduction

The test uses a multiple choice format, in which the user is asked to choose the best answer to the question given (e.g., Figure 10.6). The answers are in the form of text or in the form of graphs. In the second case, the user is asked to choose the graphic scenario that best suits the given question. The use of graphic scenarios allows for a better way for the user to apply his or her site experience in answering the questions. All of the questions in a display must be answered by the user before he or she can go on to the next questions or the results screen.
In order to prevent the repetition of questions and answers during various consultations by different users, the program includes five different sets of tests (i.e., fifty questions) to be used as preliminary tests. This will prevent the user from memorizing the test answers from another user consultation and using them during his or hers. The set of questions given will sequentially change from consultation to consultation. For example, if in the current consultation the user was given test set Number 1, the next program's user will be given the second set of test questions.
Preliminary Test Score: 3 correct answers out of 10 questions

The following are the given questions and their correct answers:

Question 1: Which of the following safety arrangements is the most desirable to prevent falls from the floor edge? (Assume all of them are equally implementable).
Answer: Scenario showing floor edge protected by guardrail system.

Question 2: Falls from the same level are more frequent than falls from a higher elevation; therefore, it can be concluded that they are more significant.
Answer: False.

Question 3: Which of the following charts best represents the relation between deaths (%), and Accident type?
Answer: Scenario showing falls accidents causing about 30% of the fatalities.

Figure 10.7: Preliminary Test Summary Display

10.7.4 The Lesson Structure

As mentioned above, the knowledge about construction falls was grouped to form lessons. Each lesson includes various related topics. The basic knowledge required by all of the users of the program is included in the tutorial part of the program. Other lessons which are related to the training topic but which are not needed by all the users are included and available in the program through the use of hyperlinks. For example, information about Experience Modification Rate (EMR) is important in order for management to understand one of the material costs of falls. However, this data is not as important to learn for workers in the site. The specific lessons and their contents are discussed in the coming sections (i.e., the tutorial or the hypermap).
10.7.5 The Tutorial Component

The tutorial part of the program includes the basic knowledge about construction falls which is needed by all users of the program. Based on our studies, we concluded that twelve lessons are required to introduce workers to construction falls, the hazardous components from which these may occur, the hazardous conditions that may lead to fall accidents, the control measures that can be taken to avoid them, the ways to select and use fall protection devices and the potential problems related to them. The following are the lessons and topics included in the tutorial program:

Lesson 1. Slips and falls in construction
Lesson 2. Slips and same level falls
Lesson 3. Higher elevation falls
Lesson 4. Role of workers in fall protection
Lesson 5. Guardrail systems
Lesson 6. Hole covers
Lesson 7. Safety net systems
Lesson 8. Fall arrest systems
Lesson 9. Warning Line Systems
Lesson 10. Control Access Zones (CAZ)
Lesson 11. Safety Monitoring Systems
Lesson 12. General safety considerations

Each lesson is divided into various related topics which are presented to the user in sequential form in order to guarantee the user will cover. In addition to these topics, each
lesson also includes a display for objectives that will enumerate all of the learning objectives he or she should have achieved by the end of the lesson.

In the program, once the user has finished the preliminary test, he or she will be taken to the lesson selection display (Figure 10.8) where he or she will be able to choose one of the ten lessons available. The lessons can be taken in any order; however, in order to get the most out of them, it is recommended that they be taken sequentially, in the same order given by the program.

Once all of the instructional topics in a lesson have been explained, a test is given to the user. The objective of the test is to evaluate how much of the knowledge provided in the lesson was retained by the user. The test consists of 5 questions related to the lesson topics. The user should get at least 3 of the 5 questions correct in order for the program to assume that the lesson was satisfactorily completed. If the score in the test is below the acceptable level, the user will be allowed to review the lesson at the end of which the user will be tested again. If the result of the test is satisfactory, the program will mark the lesson as completed and passed (i.e., grayed out in the lesson selection display). If the user fails to pass the test again, the user will be sent back to the lesson control panel where he or she can choose to return to the same lesson or to start another lesson. It should be noted that even if a lesson is marked as passed (i.e., grayed out), the user can still go back through the whole explanation part of a lesson if he or she chooses to do so. In this case, the user will not be tested at the end of the lesson again.
Each lesson has four different sets of tests which will be given as needed. A lesson will not be marked as passed until the user is able to pass the lesson test. The results of all the test scores in a lesson are kept on record for administrative uses. For example, if before passing a lesson's test, the user had to take three tests, the results of all the tests will be kept on record. These results will be useful to evaluate both the user's progress and the program's user friendliness.

10.7.6 The Information Access Component

As mentioned before, in addition to the lessons included in the tutorial lesson which are intended for all of the users, the SAFETY FIRST training program also includes
certain topics whose intended users are more limited (e.g., construction company management). These topics or lessons are included through the use of the information access component. Any supplemental information related to any of the lessons in the main tutorial is also included in this component, for example, citations and definitions of technical terms.

This component is implemented by using the hypertext and hypermedia which afford a way to incorporate non-linear information into the main program. The embedded information can be in the form of text or other multi-media components, such as diagrams, illustrations, animations, video, and sound. Further, this information can be linked and cross-referenced between each other. Finally, this information can be accessed randomly as needed by the program.

Hypertext/hypermedia consists of three main components: links, buttons or hot spots, and objects. Links are the method used to connect the information. Buttons are visible objects in the display which allow the user to jump along a link to another topic. Hot spots are similar to buttons; however, they are merged with the text or graphs. Usually, when the mouse pointer changes into a hand, that is an indication of a link to other text. Finally, objects or nodes are a part of the information network which contains a specific set of information whose size may vary. For example, a term definition, a reference, a graph, or a full blown lesson. The significance of these objects is that they allow the author to efficiently group the information.

The following are the lessons and topics included on the information access part of the SAFETY FIRST training program:
• Construction Accidents

• Accidents Definition

• Accidents Types (i.e., focus on falls)

• Fall Accidents

• Causes of Falls (i.e., Basic and Conditioning)

• Accident Costs
  - Human Costs
  - Material Costs (i.e., Direct—EMR and Indirect)

• OSHA Standards
  - Scaffolds
  - Fall Protection
  - Steel Erection
  - Ladders

• Accident Causality Models

• Fault Tree Analysis

• Accident Prevention

• Control Measures
  - Design and Planning
  - Passive Prevention
  - Active Prevention
  - Administrative Measures

• Hazard vs. Risk
• Safety Program
• Literature References
• Definitions (i.e., Glossary)

These topics can be accessed in various ways. They can be accessed from the main tutorial program via hot spots embedded in the text explanations. For example, the user clicks an active word in a text paragraph and its corresponding definition appears in a pop-up window.

They can also be accessed from the main tutorial program by selecting the button that will take the user to the hypermap display (Figure 10.9). The hypermap gives the user a general view of all the topics available in the information access segment of the program. In the map, the labeled buttons represent the information topics which can be selected to get the display containing the information about them. The lines connecting the buttons, represent a relation among the respective topics they represent. It should be noted that the topics presented in the hypermap are the major topics. Once the user accesses a specific topic, other subtopics may be available for browsing. For example, once the user has accessed the OSHA standards topic (Figure 10.10), he or she can choose other related topics, such as fall protection, scaffolding, steel erection, or ladders (see right hand side of Figure 10.10 display).

Inside the information access part of the program, topics can also accessed via cross referencing among the program’s lessons. Further, these topics can also be accessed via the glossary index which allows the user to select the topic from a list of topics (i.e., words) organized in alphabetical order (Figures 11 and 12).
10.7.7 Record Keeping Component

As mentioned before, OSHA standards require the employer to verify that the worker was trained on fall protection before being exposed to fall hazards. Towards that end, OSHA requires the employer to prepare and keep on file a written certification record which should contain the following:

- the name or other identity of the employee trained,
- the date(s) of the training, and
the signature of the person who conducted the training or the signature of the employer.

Further, OSHA also requires the employer to verify that the worker learned the information and retrain him or her, if needed.

Workers' Compensation

Workers' compensation is a form of "no fault" insurance. It was developed to provide a no-fault plan for dealing with industrial injuries. Under it employers provide insurance that pays for medical treatment, rehabilitation costs, and losses to the worker or his/her family resulting from the injury [Levit and Sunlimit 1993]. In exchange for these benefits, the worker gives up the right to sue his or her employer for negligence. Thus, eliminating many of the legal fees related to lawyer fees, trials, and appeals. Further, these laws tried to encourage employers to pay more attention to safety through the experience modification rate (EMR) mechanism.

To encourage safe behavior, under this system, employers with good accident records are rewarded by having to pay lower costs and while the opposite is true for contractors with poor records. Therefore, workers' compensation cost consist of two main components:

- The first component is a manual rate which is based on the industry sector's medical costs and benefits paid out in the previous year for each type of work (average) plus an amount to cover administrative costs of the insurance provider. This rate varies from year to year and is the same for all the contractors in the same type of work (i.e., plumbing, electrical, etc.).

Reference Source

Figure 10.10: Information Access Display
Select the first letter of the word you are searching!

Aa  Gg  Mm  Ss  Yy
Bb  Hh  Nn  Tt  Zz
Cc  Jj  Oo  Uu
Dd  Ji  Pp  Vv
Ee  Kk  Qq  Ww
Ff  Ll  Rr  Xx

Main Program
Hypermap
Exit
Return

Figure 10.11: Glossary Index Display

Select the word you are searching!

Safe  Single Locking Snaphook
Safety Belt (or Body Belt)  Slip
Safety Monitoring System  Snaphook
Safety Net  Static Coefficient of Friction
Same Level Fall  Steep Roof
Scaffold  Swing Fall
Self-retracting Line  Synthetic Fibers
Shock Absorbers

Main Program
Hypermap
Exit
Return

Figure 10.12: Glossary Items Display

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In order to prove that the knowledge given to the workers during the training session was adequate, the contractor should also maintain records of all the lesson plans, aids used to illustrate this knowledge, results of tests or quizzes, and the guidelines used to determine whether the training was successful in the short and long run. One of the advantages of using the SAFETY FIRST tutorial program is that this and other information is automatically stored and available for management for review.

The knowledge, structure, and illustrations included in the program are already available for review. Further, the use of the computer program to deliver the knowledge ensures that all trainees receive the same knowledge while allowing them to learn at their own pace. The main variable being the information provided on the hyper-lessons which the worker may or may not choose to review. In addition to this base knowledge, the first time the worker uses the program, it automatically stores the following:

1. The worker’s name, social security, and title. In order to start a training session, the worker must provide this information. The social security number of the worker will be used to store and recover all data about the worker’s training session.

2. The date of the first consultation.

3. Preliminary test data. The first time a worker uses the training program, he or she has to take a preliminary test which is used to evaluate his or her knowledge in fall protection. The results of the test also act as a baseline which in combination with the lesson test results can be used to evaluate the progress of the worker. Therefore, for this module, the program will store the following: (1) the test taken: the program contains various preliminary tests which may be given to the worker, the program will
store the questions given in the tests and the correct answers to them; (2) the results from the test: the program will store the answers given by the worker and the score he or she obtained; and (3) the amount of time it took to the worker to complete the test.

Afterwards, for every training session (i.e., every time the trainee logs into the program), the following information will be stored by the system:

1. Lesson data. In order to determine the topics the worker has been trained on, for each lesson, the program will store the following: (1) date the lesson was taken; in order to determine the time of the last training and whether the worker may need to refresh his or her knowledge, (2) whether or not the lesson has been completed (i.e., the trainee took the lesson and pass the test), (3) the estimated minimum amount of time required to read the information presented on each lesson, (4) the time spent by the trainee in the tutorial part of the lesson; the time may be used to evaluate whether the worker spent enough time trying to grasp the information presented to him or her; when compared to the estimated minimum amount of time required to completed the lesson, this information may be important to determine the reasons a worker failed a lesson test or failed to apply the lesson’s knowledge on the site, (5) the questions and answers from the lesson’s test, (6) the answers of the worker to the lesson’s test and his or her score, and (7) the amount of time the worker took to complete the lesson’s test.

2. Follow up lesson data. If a worker takes a lesson, but fails to pass the test for it, the lesson will not be marked as completed. The worker will be presented with a follow up lesson which he or she will be required to take. The following information will be
stored by the system: (1) the date the lesson was taken, (2) the estimated minimum amount of time required to read the information presented on the follow up lesson, (3) the time spent by the trainee in the lesson, (4) the questions and answers from the follow up lesson's test, (5) the answers of the worker on the test and his or her score, (6) the amount of time the worker took to complete the lesson's test, and (7) whether or not the lesson has been completed (i.e., the trainee pass the test).

3. Hyperlink lessons accessed by the trainee. The program will mark every hyperlink lesson accessed during a consultation. This may give management an idea as to the trainee level of participation and interest. It will also give the developers an idea regarding the topics of interest to the user and could be used to determine topics for future upgrades.

All of the information stored by the system will be accessible to the management representative authorized to handle those records. To access the information, the supervisor will use a separate module in the training program. In this module, the supervisor will enter the social security number of the worker for whom he or she wants to find training records. All of the training information available for the worker will be displayed (i.e., the items mentioned above).

For internal monitoring purposes, the system will give up-to-date information on every worker's training knowledge. Managers can use this information to determine whether a worker about to be transferred to a new job assignment has the adequate training required by the new job. Further, in case an accident occurs, the training records or lack of them can be used to get an indication as to whether training played a role in the
accident. If the worker was trained, the system could be used by the contractor to substantiate that the worker received adequate training. In the case of an accident, the system training records can also be used by the developer of the system to check the relevant knowledge in the program and determine if it needs further improvement. Finally, in terms of OSHA inspections, the program's records can be used to verify compliance with OSHA standards.

10.8 System Evaluation

Evaluation provides the system developers with valuable information as to the strengths and weaknesses of the system and the steps that must be taken to improve it. Similar to the expert system development, the development of a computer based training system is a continuous iterative process, as shown on Figure 10.1. At all stages of the development process, the program has to be evaluated to see whether it will achieve the final objective: effectively provide training on fall protection. Here, the evaluation process can be divided on two stages, the formative and the summative stages.

10.8.1 Formative Evaluation

At a formative or preliminary stages, the system was evaluated as to its efficiency to deliver the desired knowledge, the knowledge to be included and its organization, and the efficiency of the prototype programs. The system developers, in conjunction with experts in the field, decided on the training topics to be included, the organization of this knowledge into main lessons and supplementary lessons, and the testing methods to be
used. The main lesson topics are considered essential to a trainee, while the supplementary
(i.e., hyper-lessons) topics can supplement the trainee's knowledge, but are not essential.
The knowledge was also evaluated on its thoroughness (i.e., all topics that should be included are included), accuracy (i.e., all information presented by the system is factual; no false or misleading information is included), sequence and organization of the knowledge (i.e., main vs. supplementary lessons, topics within lessons, lessons order, etc.), and clarity (i.e., whether the knowledge presented is expected to be clear to the trainee—worker).

At the preliminary stages, a prototype of the training system was also evaluated by experts in the field of fall safety. They provided input on the program's display structure (i.e., organization, commands, appearance, etc.), features of the program (e.g., use of hyper-regions, the availability of a record keeping module, etc.), delivery methods (e.g., graphics vs. text only), among others. They tried to identify the weaknesses and strengths of the system, the objective being to eliminate the weaknesses by adding new features or modifying current ones and strengthening the ones that are good. The continuous evaluation of the system at early stages made major modifications less likely at later stages of the development process.

10.8.2 Summative Evaluation

Later, once the final program was in the later stages of development where all the internal functions that drive the program have been developed and a final structure for the user interface have been set (i.e., the program is ready to be delivered), the summative stage of evaluation starts. The objective of this evaluation is to determine whether the
system as it is will be easy to use and fulfill the final objective of training the user.

According to Watson [1979] the following areas of a training program merit evaluation:

1. the reactions of the trainees to the training system and their learning experience,
2. the trainee learning and whether their knowledge and attitudes changed as a result of the training,
3. the on-the-job behavior of the trainee after the training. Did their safety practices improve as a result of the training?, and
4. the impact of the training on the organization. Did any other improvements occur as a result of the training program? For example, did the workers attitude towards safety and their relation with management improve?

10.8.2.1 Evaluation of Reactions

The user perception of the program can influence the likelihood they will use it. If they perceive the system as useful and interesting, they are more likely to use it. After using the system, the users can provide a valid assessment of the degree to which the training system met their expectations, the accuracy of the knowledge, the approaches and delivery methods (e.g., text vs. graphics, hyper-links, etc.) used that they found more useful, their perception of the overall system, the testing methods used, etc.

The trainees level of knowledge on the area where they are being trained is limited; therefore, in addition to their reactions, the reactions from experts on the field of construction safety is obtained. They will evaluate the same aspects of the program the trainee does; however, they can provide a better assessment of the thoroughness, validity,
and accuracy of the knowledge presented in the system. The next section presents the evaluation sheet developed to gather the trainee and experts reactions to the system.

10.8.2.2 Evaluation Format

In order to get the reactions to the training system, a formal evaluation sheet was created to evaluate the system (See Appendix D). The form features requires three data about the evaluator: the name, his affiliation, and his position. Of these, the name is optional (some evaluators are reluctant to provide their names). The affiliation and position are used to determine the level of expertise of the evaluator on fall protection. Next, the purpose of the form, how it relates to them and how it will be used by the system developer is explained. This is to make the importance of the evaluation clear to the person filling it.

The form ask the user to evaluate the four main modules of the program: preliminary test, main lessons, hyper-lessons, and record-keeping. Each of these modules is evaluated according to various criteria that applies to them (e.g., knowledge, user interface, questions and answers). Within the form, a specific definition of the criteria is given in order for the user to evaluate it.

As with the expert system's evaluations, five logic expressions were provided for the evaluation of each criteria: very good, good, fair, poor, and very poor. The following are the guidelines given to the user as to how to use the rating:

- Very good: little or no improvement is required
- Good: some improvement is required but no major mistakes are detected.

- Fair: some problems are detected but performance is satisfactory.

- Poor: major changes are required.

- Very poor: redevelopment is required.

In addition to rating the criteria, the users are given space and encouraged to explain their ratings or provide any relevant comments.

In addition to the individual modules, the overall structure of the system is also evaluated for efficiency and applicability, including the feedback provided by the system, the ability of the user to control the information presented, the ability of the user to foresee the potential actions available at a given time, the response times of the system, and the overall quality of the system. The same rating methods are used to evaluate these factors. Finally, the users are asked four open-ended questions to get their overall impression about the following: the positive aspects of the system, the negative aspects of the system, the worthiness of the system, and whether they would recommend the system to their peers.

The system evaluation was performed by experts (i.e., first evaluation group) who could evaluate the accuracy of the knowledge presented by the system and by potential trainees (i.e., second evaluation group) who could provide input on the programs structure and usability.
10.8.2.3 Evaluation Results

As mentioned in the previous section, two groups of people evaluated each of the four main components of the system. The first group consisted of six experts in the construction safety field. Of these experts, three act as safety managers for their respective contracting companies, two of them are private safety consultants, and one is one of the people in charge of safety matters for the builder's exchange. The second group of evaluators consisted of nine students from the construction engineering and management program at The Ohio State University. Their experience levels range from no site experience to up to ten years of experience. The students with experience having jobs which ranged from workers (i.e., three students) to site supervisors.

The system was evaluated in terms of the knowledge or information it presents and the user interface. In general, all of the system's components features were rated between good and very good by both evaluating groups. For the second group, some of the evaluators did not evaluate some of the knowledge related criteria because of lack of knowledge in fall protection. Figures 10.13 to 10.51 show the evaluation results for the first group of evaluators; while, Figures 10.52 to 10.90 show the results of the same evaluation for the second group.

Concerning the preliminary test, the evaluators agreed that the multiple-choice format used to get the trainees answer, and that the questions and answers provided were relevant to the topic and clear. However, they suggested that during the test feedback the system should highlight the question(s) the user answer incorrectly. The developers agreed
with this suggestion and this functionality has been incorporated in the program. As for
the user interface, it was evaluated to be between good and very good.

For the second component (i.e., main lessons), three major factors were evaluated:
the knowledge, the user interface, and the lesson tests. In general, the main lesson’s
knowledge was seen as a major strength of the program. Most experts rated the
knowledge-related items to be very good. There were some concerns regarding some of
the terms used in the program. These concerns have already been addressed in the
program. The user interface was also highly rated by both groups of evaluators. However,
some evaluators indicated that one of the color schema (i.e., dark blue text on a light blue
background) used in the lesson displays was rather difficult to read. As a consequence, this
color schema has been modified to present a higher contrast. Finally, the lesson tests were
also rated highly.

As for the supplementary lessons component, the experts gave their best rating to
the knowledge (i.e., thoroughness and accuracy) included in this component. Regarding
the user interface, most experts evaluated it to be between good an very good; however,
one of the experts indicated that the font size used to present the knowledge was too
small. Thus, he rated the information readability to be fair. Given that this problem was
also orally addressed by the other evaluators, the developers decided to modify the
program to address this problem. During the second evaluation by the students, the user
interface was rated as very good by most evaluators.

All of the features in the record keeping module were rated between good and very
good. During one of the evaluations with the first group, this module exhibited some
glitches which have already been addressed by the developers. During the second
evaluation, this and other glitches identified during the first evaluation were not a problem
again.

Finally, all evaluators (i.e., from both groups) rated the overall quality and
potential usefulness of the system to be better than good. In the first group, 80 percent of
the evaluators rated the overall quality of the system as very good; while, in group 2, over
90 percent of the evaluators rated the overall quality of the system as very good.

The evaluation form also included four questions intended to get the evaluators
opinion of the positive and negative aspects of the program and its worthiness to the
industry. The following are some of the program's positive aspects named by the
evaluators:

"The system is easy to use. My computer literacy is limited to using general
programs as opposed to programming. However, I feel someone with very
basic skills should have no problem, or a person with no skills would be
able to use the program after instructions on how to use the mouse."

"Easy to use by anyone familiar with window based programs."

"You are well on your way to developing a very solid, practical training
tool that could become a very valuable resource for the construction
industry."

"Would give a person with limited knowledge on fall protection, a valuable
source of information without requiring additional reading resources."

"Contains all the needed fall protection training."
"Definitely a positive pro-active approach."

As for the negative aspects of the program, most of the comments were related to the program interface, such as color contrast and font sizes used. One of the evaluators indicated he encountered some problems with the record-keeping module stored information (i.e., some of the information stored did not match the training session). Finally, some of the evaluators expressed concern as to the program’s usage:

"Most of our employees who would take this test do not have any computer background and would be very hesitant to participate."

"This would be good for safety directors but for the average construction worker this would be very time consuming."

Other comments indicated that the program should emphasize that this is a general training tool and the worker should get site specific training to recognize unusual hazards that may exist in a site. Despite all of the comments above, all of the evaluators agreed that this program would be worthwhile of their or their employee’s time and indicated they would recommend it to their peers.

10.8.3 Learning Evaluation

As for the evaluation of the user’s learning, the system provides a basic infrastructure to evaluate the user’s knowledge before and immediately after using the training system. To do this evaluation the system uses multiple choice tests which can be used to test the users’ knowledge and monitor their progress as they go through every
lesson in the system. As mentioned before, the information related to the preliminary and lesson tests is stored by the system and is always available to be checked by management.

The use of a pretest and post-test method to evaluate the user learning provides a basic structure that could be used to evaluate the learning resulting from the program. The pretest result, when compared to the results of the lesson post-tests, gives a baseline that can be used to evaluate the progress or lack of progress by the trainee.

The conclusions about the user's learning can be strengthened further if one step is added to the evaluation process and the trainees are randomly divided into two groups. The first group is given the training including all of the tests while the second group is asked to take all of the tests without going through the training process. This method would allow the developer to compare the rate of improvement resulting from the training process (i.e., difference between the preliminary and post tests. If the improvement observed in the trained group is better than that for the control (i.e., untrained) group, it could be concluded that the training system improved the worker's knowledge. In the recommendations for future studies, the author suggests the development of such test to further evaluate the SAFETY FIRST training system.

10.8.4 Evaluation of On-the-job Behavior and Impact on Organization

Once the workers are back on the job site, the application of the new training knowledge to their daily practices can be evaluated. The on-the-job behavior of the worker could be evaluated by using behavior observation sessions where the workers' safety behavior is monitored unbeknown to them to determine whether they are applying
the new knowledge. Another way to evaluate the on-the-job progress of the worker is to use questionnaires to ask both workers and their supervisors whether the safety training changed their behavior and, if not, the reasons it did not. For example, the working environment does not encourage the use of these safety practices (e.g., the safety devices required are not available in the site).

If the reasons for the lack of application of the training practices is not directly related to the training system itself, but the working environment and practices of the company, these practices and policies must be reviewed and modified to support the behavior taught during training (e.g., develop a safety program for the company—see Chapter 2). For example, there is no use in workers knowing the advantages of wearing fall arrest equipment, if this equipment is not available in the site for their use. On the other hand, if the lack of application can be traced to the training system, the weak points of the system must be identified and improved.

Several of the methods discussed in Chapter 2 can be used to evaluate the impact of training on the organization (e.g., accident rates, the experience modification rate, the worker efficiency and productivity, and the relationship between management and workers). The impact could be positive if the worker is encouraged by the working environment to use the knowledge they acquired during the training. On the other hand, if the working environment does not encourage the use of this knowledge, the impact could be negative as the worker grows frustrated to the obstructions to their attempts to follow safe practices. The worker knows the potential consequences of the unsafe practices to his or her life, but is forced to follow them.
Figure 10.13 Preliminary Test’s Format

Figure 10.14 Preliminary Test’s Questions and Answers

Figure 10.15 Preliminary Test’s Relevance of Questions and Answers to the Topic

Figure 10.16 Preliminary Test’s Feedback

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Figure 10.17 Preliminary Test's Color Usage of the User Interface

Figure 10.18 Preliminary Test's Screen Layout of the User Interface

Figure 10.19 Main Lesson's Thoroughness (Fall Safety Knowledge)

Figure 10.20 Main Lesson's Accuracy (Fall Safety Knowledge)
Figure 10.21 Main Lesson’s Sequence and Organization (Fall Safety Knowledge)

Figure 10.22 Main Lesson’s Clarity (Fall Safety Knowledge)

Figure 10.23 Main Lesson’s Color Usage of the User Interface

Figure 10.24 Main Lesson’s Screen Layout of the User Interface
Figure 10.25 Main Lesson’s Amount of Information

Figure 10.26 Main Lesson’s Readability of the User Interface

Figure 10.27 Lesson’s Use of Graphics of the User Interface

Figure 10.28 Lesson’s Test Format

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Figure 10.29 Lesson’ Test Question and Answer

Figure 10.30 Lesson’ Test Relevance of Question and Answer to the Topic

Figure 10.31 Lesson’ Test Feedback
Figure 10.32: Supplementary Lesson’s Thoroughness of the Knowledge

Figure 10.33: Supplementary Lesson’s Accuracy of the Knowledge

Figure 10.34: Supplementary Lesson’s Sequence and Organization of the Knowledge

Figure 10.35: Supplementary Lesson’s Clarity of the Knowledge
Figure 10.36: Supplementary Lesson's Color Usage of the User Interface

Figure 10.37: Supplementary Lesson's Screen Layout of the User Interface

Figure 10.38: Supplementary Lesson's Amount of Information

Figure 10.39: Supplementary Lesson's Readability of the User Interface
Figure 10.40: Record Keeping Module’s Thoroughness of the Information

Figure 10.41: Record Keeping Module’s Accuracy of the Information

Figure 10.42: Record Keeping Module’s Sequence and Organization of the Information

Figure 10.43: Record Keeping Module’s Color Usage of the User Interface
Figure 10.44: Record Keeping Module’s Screen Layout of the User Interface

Figure 10.45: Record Keeping Module’s Amount of Information

Figure 10.46: Record Keeping Module’s Readability

Figure 10.47: System’s Efficiency and Applicability of the Feedback
Figure 10.48: System’s Efficiency and Applicability of the User Control

Figure 10.49: System’s Efficiency and Applicability of the Potential Action

Figure 10.50: System’s Efficiency and Applicability of the Response Time

Figure 10.51: System’s Overall Quality
Figure 10.52 Preliminary Test's Format

Figure 10.53 Preliminary Test's Questions and Answers

Figure 10.54 Preliminary Test's Relevance of Questions and Answers to the Topic

Figure 10.55 Preliminary Test's Feedback
Figure 10.56 Preliminary Test’s Color Usage of the User Interface

Figure 10.57 Preliminary Test’s Screen Layout of the User Interface

Figure 10.58 Main Lesson’s Thoroughness (Fall Safety Knowledge)

Figure 10.59 Main Lesson’s Accuracy (Fall Safety Knowledge)
Figure 10.60 Main Lesson's Sequence and Organization (Fall Safety Knowledge)

Figure 10.61 Main Lesson's Clarity (Fall Safety Knowledge)

Figure 10.62 Main Lesson's Color Usage of the User Interface

Figure 10.63 Main Lesson's Screen Layout of the User Interface
Figure 10.68 Lesson’ Test Question and Answer

Figure 10.69 Lesson’ Test Relevance of Question and Answer to the Topic

Figure 10.70 Lesson’ Test Feedback
Figure 10.71: Supplementary Lesson’s Thoroughness of the Knowledge

Figure 10.72: Supplementary Lesson’s Accuracy of the Knowledge

Figure 10.73: Supplementary Lesson’s Sequence and Organization of the Knowledge

Figure 10.74: Supplementary Lesson’s Clarity of the Knowledge
Figure 10.75: Supplementary Lesson's Color Usage of the User Interface

Figure 10.76: Supplementary Lesson's Screen Layout of the User Interface

Figure 10.77: Supplementary Lesson's Amount of Information

Figure 10.78: Supplementary Lesson's Readability of the User Interface
Figure 10.79: Record Keeping Module’s Thoroughness of the Information

Figure 10.80: Record Keeping Module’s Accuracy of the Information

Figure 10.81: Record Keeping Module’s Sequence and Organization of the Information

Figure 10.82: Record Keeping Module’s Color Usage of the User Interface
Figure 10.83: Record Keeping Module’s Screen Layout of the User Interface

Figure 10.84: Record Keeping Module’s Amount of Information

Figure 10.85: Record Keeping Module’s Readability

Figure 10.86: System’s Efficiency and Applicability of the Feedback
Figure 10.87: System’s Efficiency and Applicability of the User Control

Figure 10.88: System’s Efficiency and Applicability of the Potential Action

Figure 10.89: System’s Efficiency and Applicability of the Response Time

Figure 10.90: System’s Overall Quality
CHAPTER 11

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

11.1 Summary

As stated in Chapter 1 of this report, the objective of this research was to develop a PC Based program that could be used to control fall accidents. The program is a four-prong means of investigating and improving fall protection: investigation of fall accidents, evaluation of site fall safety conditions during construction, preventive design and planning measures to avoid falls during and after construction, and a computer based training system that incorporates all the knowledge compiled about the causes of falls and how to avoid them.

In order to develop this system, the first step was to become familiar with all aspects of fall protection in construction. Three types of accidents were studied: falls from the same level, falls from higher elevation, and slips (without falling). From reports on the elevated locations from which most fatalities due to falls occur and knowledge from experts in the construction safety field, the following elevated components were selected for study: roofs, form scaffolds, steel beams, floor edges, floor openings, portable ladders, wall openings, and tops of walls. For this study the scope was limited to falls that occur during vertical construction operations, such as during the construction of commercial
buildings or residential homes. Hence, events such as falls during bridge construction, falls during trench operations, and falls from utility poles were beyond this study's scope.

The focus of the study was on worker-related causes of construction falls (i.e., enabling, triggering, and support related causes). Worker enabling causes (i.e., causes internal to the worker) and worker triggering causes (i.e., due to external events acting upon the worker) are discussed in detail. Support-related causes are classified into those related to the collapse of the support structure and those that could cause worker slips or trips. Of these causes, the latter were explored in detail. As for the potential causes of a structure collapse, we limit our scope to identifying the failing component and the general cause of failure (enabling—internal, triggering—external, or support-related). However, for portable ladders and form scaffoldings a large percentage of fatalities and injuries are due to the structure failure; hence, for these components, these causes are explored in detail.

Further, the conditioning causes of falls were investigated. These are causes related to safety problems in the site. They are related to general safety problems, such as housekeeping and personal protective equipment problems; or fall protection problems which depend on the elevated component being investigated and the fall protection device being used (if at all).

The knowledge about these accidents and components was obtained through a systematic knowledge acquisition process during which both literature and expert's knowledge was obtained and used to develop fault tree structures which organized the knowledge in a systematic way to illustrate the potential causes and events which could
contribute to the occurrence of undesired falls. To develop a fault tree, the analyst starts with a top undesired event (e.g., worker falls from the same level) and deductively tries to determine the events or causes contributing to its occurrence. The way these events or causes interact to produce the top event is represented through the use of logic gates (i.e., OR, EXCLUSIVE OR, AND, and INHIBIT gates). Each gate symbolizes the logic relation between the input event (lower level event) and the output event (higher level event). Using this technique, the reasonable and significant parallel and sequential combinations of potential causes (basic or conditioning) of falls were established. A total of ten fault tree models were developed in this study: one for same level falls, one for slips, and eight for elevated component falls.

As discussed above, the SAFETY FIRST system consists of four modules: investigation, evaluation, design and planning, and training. Of these, the first three modules are developed using expert system techniques. The training module is a computer based training system which incorporates the knowledge obtained from the previous modules and uses it to teach construction workers and managers.

Regarding the expert system modules the research methodology used to develop them included four major steps: knowledge acquisition, knowledge representation, system implementation, and testing and evaluation. The knowledge acquisition step involves the process of obtaining the knowledge required to develop the expert system. This knowledge was acquired by the author and his advisor which acted as the knowledge engineers for this project. There are two groups of knowledge engineers: elicitors who interview the experts and elicit their knowledge, and programmers who convert this
knowledge into a computer program. The experts are people whose knowledge and experience in the area of interest is above that of an average peer.

The knowledge acquisition process was divided into four major phases: preliminary, intermediate, advanced, and organization. During the preliminary phase, the feasibility and applicability of expert system technology to the problem at hand was assessed. This process included determining if the knowledge required to solve the problem was mainly heuristic in nature, if the scope of the problem was well defined and limited (e.g., select elevated components to be studied), and if the expertise required to develop the program was available. This phase also involved reviewing existing literature on fall protection and choosing, contacting, and interviewing experts for the project. The experts were selected based on their knowledge, experience, and availability. These experts are recognized as knowledgeable in the general area of safety, and specifically, in construction falls. Further, they had to be willing to make themselves available for the acquisition process.

During the intermediate phase, the knowledge engineers focused on experts' knowledge regarding the subject matter (construction falls). In this phase, a questionnaire was developed with the objective of acquiring domain-specific information from the experts. Further interviews focused on reviewing information obtained previously, clearing potential misconceptions or conflicts of opinion among experts and refining the knowledge obtained. After several interviews, a general representation of the experts' thought processes was developed.
The advanced phase allowed the knowledge engineers to refine the knowledge by going over specific details which needed to be clarified or which caused disagreement among the experts. Finally, the organization phase acted as a link between the knowledge acquisition task and the knowledge representation task. In this phase, the knowledge acquired from the experts was converted into preliminary graphic models to represent the experts’ knowledge regarding the causes of construction falls.

The next step in the expert system development process was the knowledge representation. For the investigation and evaluation modules, this step was accomplished in two steps: first, the knowledge acquired was structured as fault tree structures, and second, it was restructured as decision structures which are made up of a combination of decision trees and decision tables. The fault trees reveal a causality pattern which represent the process by which experts diagnose a fall. The decision structures developed incorporate this causality knowledge and incorporate other variables and parameters needed by the system to reach a conclusion. For example, observable signs needed to infer whether a potential cause played a role in an accident. For the design and planning module, though some of the knowledge represented in the fault trees was basic information, the decision structures developed to represent this knowledge were developed based on the specific knowledge acquired from experts and some limited literature.

As for the system implementation, SAFETY FIRST was developed in an expert system shell (i.e., Level 5 Object), with major components, such as the inference mechanism, the knowledge base, user interface, and facilities for external files interface.
The inference mechanism, often called the "brain" of the system, comes with the shell. The knowledge base serves to store the body of knowledge. The development of the knowledge base encompassed knowledge conversion from the decision structures into objects (i.e., classes, instances, and attributes), production rules which control the knowledge flow of the program, and "when changed" method that are chunks of procedural code executed as needed by the program. SAFETY FIRST was also developed with its users in mind; hence, throughout its development, emphasis was also placed on user interface. Screen displays were carefully crafted so that users would feel comfortable in interfacing with the system. In each screen, terms that may not be too clear for first time users and novices in construction safety are furnished with detailed explanation. Further, in each display, the user can query the system as to the purpose of the current question in the overall schema or how the system reached a specific conclusion. Messages, graphics, hyperlinks, and help statements are abundant and readily accessible to the users. In addition to the knowledge accuracy, throughout their development and upon their completion, the expert systems' performance was evaluated in terms of the conclusions accuracy and level of explanations furnished. In addition, the system's questions, user interface, explanation facilities, efficiency, and applicability were evaluated by independent experts and potential users.

As for the training module of the SAFETY FIRST program, it is developed as a computer-based training program using Computer Assisted Instruction techniques. The research methodology used to develop this module involved four major steps (see Figure 10.1): needs assessment, system planning and design, and system evaluation. During the
needs assessment phase, the following factors were examined and assessed: the safety training needs in the construction, the role of training in construction safety, the current status of training in the industry (including practices currently used, such as safety videos and toolbox meetings), and the potential delivery systems (e.g., lectures, tutoring, on-the-job training, and computer assisted instruction) and their strengths and weaknesses for educating workers and managers in fall safety. It was concluded that a computer assisted training program would be able to deliver the safety knowledge in a timely (i.e., whenever needed), consistent (i.e., all the knowledge required will be delivered and always in the same manner), and interactive (i.e., it uses mixed delivery strategies) manner which makes it more likely to be effective. Further, this kind of program has the potential to adapt to the user's current knowledge level and provides facilities to test the user's progress. Finally, the training system can be used as a consulting tool when accessed from one of the recommendation displays of the expert system modules. In that case, the program does not maintain training records and the user is not asked to take any tests.

The training program consists of four major components: preliminary testing, main lessons training, hyper-lessons, and record keeping. The preliminary testing component has the objective of providing a base line of the fall safety knowledge the user had before going through the program. The system will provide the user with 10 multiple choice questions which may involve graphic (e.g., choosing the best safety scenario from various graphical scenarios presented) or textual choices. The preliminary test is taken once by the user and its result is stored by the program for future reference. Once the user has taken the test, the user can access the main lessons component of the program. This component
includes all the information determined to be essential for fall protection training of a user (i.e., a total of twelve lessons). Each lesson contains two components: main body where the knowledge on the lesson is presented in various text and graphic formats, and a testing facility where the user's understanding of the topic at hand will be checked. A lesson will not be marked as passed by the user unless he or she achieves a minimum score on this test. As the user is taking a specific lesson, he or she can also access the hyper-link lessons component which includes 30 additional lesson topics related to general accident theories, fall safety, and current codes. Further, this component contains a glossary of technical words and references used throughout the program. Finally, the record-keeping module will store the information about the user's consultation. The automatic record keeping allows management and inspectors from government agencies (i.e., OSHA) instant access to the employee training records (e.g., the lessons accessed and completed, the time spent on the lessons, and the tests taken and the scores achieved).

As with the expert system modules, the training module was developed with its users in mind; therefore, the user interface design and development was a major priority on the implementation process. Further, each component in the training module was evaluated in terms of knowledge accuracy and system performance. Given that one of the expected users of this module are construction workers, a great deal of emphasis was placed on evaluating all aspects of the user interface.
11.2 Conclusions

Although falls are the most significant cause of death and injuries in the construction industry, the literature review performed for this study revealed that their causes have not been studied in detail. For this study, a system analysis (i.e., fault tree) was used to determine the potential causes or combination of causes leading to falls from higher elevation, falls from the same level, and slips.

Regarding the causes of falls, it was found that two major types of causes play a role in falls and slips: basic and conditioning causes. Basic causes are those which by themselves or in combination with conditioning causes can cause a fall. Conditioning causes are causes related to problems with the safety measures implemented in the site. They are important because their elimination (i.e., by implementing adequate safety measures) may be enough to prevent an accident from occurring.

It was also found that the worker-related basic causes of a fall are similar for all of the elevated components; however, the significance of these causes varied depending on the elevated component being studied. Further, conditioning causes of falls varied both among the various accident types (i.e., elevated and same level falls, and slips) and the elevated components (e.g., roof or floor edge). The emphasis of the conditioning causes for elevated falls is on the fall protective or preventive equipment provided to control such incidents. In contrast, for same level falls and slips, the focus is on the general safety measures implemented in the working area, including overhead protection from falling objects, housekeeping practices, and personal protective equipment used, among others.
More specifically, this study found that the basic causes of falls as they relate to the worker could be classified into enabling, triggering, and support-related. The enabling causes are related to problems internal to the worker. These problems were grouped into health, attitude, and skill problems. Health problems include physical problems which suddenly or over time may affect the worker and cause a fall. These problems include cases in which the worker falls due to a sudden illness that could result in a collapse and fall. Examples of sudden illnesses are heart attacks and fainting. Another cause of falls is a chronic illness that acts on the worker over time, weakens and causes his or her concentration and the ability to recognize hazards to diminish. A third cause that appears among the health problems is the case when the worker used over-the-counter drugs that caused him or her to be drowsy or sleepy during a construction operation. Finally, there is the case in which an excessive work load causes the worker to become fatigued and collapse or lose some of his or her concentration. Attitude problems are related to the worker’s attitude towards his or her job or life in general. They can be further divided into the following problems: cases in which the worker is not in full control of all of his or her senses, such as when he or she is drugged (after using an illicit drug like cocaine) or drunk; cases in which the worker’s personality causes his or her fall, for example when he or she does not follow the supervisor’s instructions or ignores established safety procedures; and cases in which psychological (stress, personal, or financial problems) or environmental (related to events happening in work zone surroundings) distractions cause him or her to fall. Finally, skill related problems are related to the capacity of the worker to recognize and react to latent hazards on the site. These problems happen when the
worker lacks training or experience. All experts agreed that the more experienced the worker is, the less likely he or she is to fall. The worker's experience allows him or her to identify hazards and to know what measures to take to avoid the fall. However, experts warned that some times experienced workers get overconfident and careless. If that is the case and the worker falls, we can classify this fall within the attitude causes of fall. Finally, a lack of skill by the worker may be caused by problems with the worker's capacity to learn from experience and training. This case would be similar to the case in which the worker falls due to lack of training or lack of experience.

As for the triggering causes affecting the worker, they include any external event acting on him or her and causing the fall. Under the triggering causes, we studied the potential of having a worker hit by another worker, by a piece of material, or by a piece of equipment, and when environmental conditions are the cause of a fall. Under the environmental conditions, we included any natural event that could lead to the worker's fall, including strong winds (gusts), rain, hail, snow, frost, fog, extreme cold, and extreme heat. These factors can lead the worker to fall in different ways. The gust or strong wind may cause the worker to fall due to its impact force. Fog may reduce the worker's visibility and cause his or her fall, whereas other conditions, like rain and frost, may cause slippery conditions which favor the occurrence of falls. Extremely cold or hot conditions could be the cause of accidents just by reducing the concentration and care with which the worker performs his or her job.

The final basic cause group, support related causes, includes causes of falls related to the component supporting the worker while he or she performs a job. These causes
vary depending on the component assumed to be supporting the worker. These support components are defined for each of the fault tree structures developed. There are two main types of support related problems: first, problems that due to their seriousness may cause the collapse of the whole support structure or one of its components, hence leading the worker to fall; and second, problems related to the support component (e.g., floor) which could lead to a worker fall without causing the structure or its components to collapse (e.g., slipping or tripping hazards). Given that more of the structures analyzed are permanent parts of the building, collapse-related falls are not very common; therefore, these causes were not developed in great detail, and in most cases were merely mentioned.

In the case of falls from ladders and form scaffolds these causes are important since many falls are due to the support component’s collapse. To analyze these causes, the system was divided into subcomponents (e.g., form scaffold is divided into planks, brackets, and formwork) and each subcomponent was examined in terms of enabling (i.e., internal), triggering (i.e., external), and support related problems.

The conditioning causes are related to safety problems that enable the basic causes to be a factor in the worker’s fall. However, these causes alone are not likely to cause the worker to fall. In the case of falls from higher elevations, these causes are mainly related to the fall safety systems on the site. Two main problems relate to the fall systems. The first is when no fall protection or prevention devices are provided to prevent or reduce the chances of worker fall accidents. The second problem is when the fall protection or prevention device provided is not adequate. These problems vary depending on the device being used, but in general can be grouped into problems related to inadequate
material components, inadequate installation, or inadequate use. Among the fall protection or prevention devices often used in elevated components are standard guardrails, catch platforms, opening covers, fall arrest systems, safety nets, warning lines, and control access zones.

In the case of same level falls and slips, the lack or inadequacy of fall protection devices is not significant. The conditioning causes related to general safety problems in the working surface are more important. Among these problems are problems related to lack of overhead protection on the working surface or lack of toeboards or guards on the upper working surfaces to prevent workers from being hit by falling objects. Housekeeping problems, such as the failure to keep the area clear from obstacles, spills and small objects, tools and materials that could cause a worker to trip or slip and possibly fall. Personal protective equipment problems related to the lack or use of inadequate protective equipment. For example, not using hard hats in areas where falling objects may occur or using shoes that do not have slip resistance strips. Finally, there are problems related to general safety practices of the contractor, such as lack of a safety policy to detect health problems or alcohol and drug abuse problems, and lack of training programs to educate workers on fall protection.

Other salient features regarding the causes of unintentional worker falls that were obtained from this study are as follows:

1. Triggering causes due to environmental factors (rain, fog, etc.) often play a significant role in causing falls from roofs, steel beams, and tops of walls. This is due to the fact that such components are usually exposed to these factors.
2. Enabling and triggering causes can play a significant role in falls from steel beams, top of walls, and portable ladders. This is due to the limited working surface where the minimal lapses in concentration could be fatal. Further, there is usually little space and time to react to hazards.

3. If a roof is surrounded by a parapet wall at least 3 feet (.914 m) high, there is no need to provide additional protection along the edge. Skylight openings of a roof are not designed to take heavy working loads. They should be protected with some fall protection device. The lack of such protection could be a conditioning cause of a fall.

4. For portable ladders, enabling causes (attitude or skill) play an important factor in worker falls. If the ladder is not high enough or incorrectly placed, a worker may have a tendency to over-reach from the ladder and, in turn, may cause the worker to fall. For a self-standing ladder, the worker's tendency to stand or sit on the ladder top is also a common problem.

5. Fall protection or prevention devices are rarely used for portable ladders. However, experts recommend that the worker should always keep three contact points with the ladder (two hands and a foot, or two feet and a hand). If the worker needs both hands to perform his or her job, experts recommend the use of safety belts or body harnesses.

6. For falls from the same level, support-related (i.e., slips and trips) and triggering (impact) causes are the main causes of falls.

7. For slips, the main cause of falls is the low friction between the shoe and the working surface. This low friction could be caused by the presence of spills, small objects, and debris on the floor; or the use of inadequate shoes at the work site.
8. Falls from a form scaffolding can be largely caused by the scaffolding collapse. This collapse could be caused by material problems (e.g., use of planks that are not scaffold grade and therefore not weather resistant), installation problems (e.g., missing support components such as bracings), and misuse problems (e.g., placing excessive loads on the scaffold).

The identification of the causes of construction falls from hazardous working components most frequently encountered during construction operations is expected to benefit those concerned with construction safety to take appropriate countermeasures in order to reduce the number of falls, and eventually, to achieve a safer working environment.

The knowledge about the causes of falls was obtained from both literature and experts. This knowledge was represented using fault tree models which simulate the various reasoning paths of experts when trying to reach a conclusion as to the contributing causes of falls. Further, these models provide their users with a template which they can use to trace the various events and causes that could contribute to a fall accident.

Like any other method, the fault tree approach has its limitations. The concept of fault tree analysis was originally developed for event-oriented systems, such as those frequently used to assess system and nuclear safety. Therefore, causes are determined in terms of events. When used in construction, this concept has a limitation since causes of an accident may be events or non-events. Hence, in order to apply this approach to construction or structure-related faults, we enhanced the concept to accommodate both events and non-events, by classifying them as enabling, triggering, and support-related
causes. Events are generally classified into “triggering” causes, while non-events are classified into “enabling” causes.

Further, while developing the fault tree models, we noticed that the extent of the expansion is unlimited. Therefore, the analyst must use his or her judgment as to where to stop expanding the fault tree. In order to avoid omissions of important causes of falls, several experts in the area of falls and construction safety were consulted during the fault tree development process.

Finally, it can be concluded that the fault tree models developed offer a systematic and analytical representation of the causality relationships that could lead to fall accidents and that they are a fair representation of the way experts assess fall accidents and potential fall hazards. These fault tree models are the basic representation structure of the relationship among the various factors that may cause falls.

The fault tree models provide a clear picture of the specific causes or combination of causes that may cause the top undesired event (i.e., fall or slip). However, in order to investigate the causes of a particular fall accident or evaluate the fall safety in a working area, experts must also consider observable signs and other specific parameters and variables that may be used to infer whether a particular basic cause played a role in the accident or to reduce the search tree (e.g., if an expert is investigating the cause of a fall from a floor edge guarded by a guardrail, the guardrail’s condition after the fall is an observable sign which may indicate whether the material problems, installation or use problems contributed to the fall).
Therefore, in order to incorporate the knowledge in the fault trees to the expert system modules to investigate falls and evaluate fall safety, this research proposes a decision structure that includes both the causality knowledge depicted in the fault tree and other knowledge (i.e., signs and facts) needed to reduce the search tree or infer certain variables. These decision structures use a combination of decision trees and decision tables to determine the most likely cause of the accident being investigated. They outline the decision paths the expert system program may take to reach a conclusion. Therefore, they allow for a clear understanding of the reasoning path and easy verification as to the knowledge accuracy. Further, they allow the knowledge engineer to easily transform the knowledge into the classes, instances, attributes, and production rules used to incorporate the knowledge into the knowledge base of the expert system.

As for the design and planning expert system, the idea of developing this module came from the current CDM regulations adopted by the European Community, which require designers to consider potential health and safety hazards at early stages of the project design and places the burden on them to eliminate these hazards (i.e., choose alternative designs) or bring them to the contractor’s attention with recommendations on how to handle them. The objective of this module of the program is to make the designer aware of certain areas in the design of multi-story buildings where their choices could improve fall safety conditions. Further, the program outlines planning considerations which could help eliminate or reduce fall hazards. In terms of fall safety, the following are the most significant design factors identified in this study:
1. Whenever all other factors are equal (e.g., cost, aesthetics, etc.) flat or low sloped roof structures are a preferred option to steep or sloped roof structures.

2. Regardless of the type of roof structure (i.e., flat or steep), a simple practice that could greatly reduce falls from roof edges would be the design of a parapet wall 39 inches (1020 mm) high on the roof perimeter. In the case of steep roofs, if such a wall is used, the design should increase the structure’s load bearing capacity (i.e., for snow accumulation) or provide mechanisms to prevent snow accumulation.

3. For steep roof structures, access to the roof should be available from the interior of the building (i.e., as supposed to the edge). Further, the roof structure should have an anchorage point designed at a point where the worker can tie up before walking into the roof.

4. For building structures higher than 3 stories, according to expert’s opinion, the roof structure should have built in anchorage points throughout the roof perimeter. These anchorages will be used for future maintenance of the building.

5. For structural steel framed structures, the column design could incorporate built in anchor points which could be used by steel erectors to tie up. Further, the columns could also have built in holes at 42 inches (1100 mm) and 21 inches (550 mm) high to accommodate the erection of a wirerail system on the floor perimeter [Hinze 1997].

6. Finally, prefabricated wall structures could be designed in to reduce the exposure time and the potential for falls and falling objects. It has been suggested that this method of erection is cost effective and faster than traditional practices.
As for the planning considerations, the following are some of the factors the designer could highlight on their hazard reports:

1. If the roof structure being built has permanent anchorage points designed in, these anchorage points should be installed early on the construction process, so that they can be used at later construction stages.

2. Whenever any work has to be performed on a steep roof not protected by a parapet wall, a temporary anchorage structure (e.g. horizontal lifeline) should be set up as a tie up point for workers.

3. The load bearing capacity and condition of the roof must be considered before bringing working materials onto the roof. This is to prevent roof failures (a major cause of worker falls from roofs).

4. If the only access point to the steep roof is its perimeter, catch platforms could be set up to protect the roof edge.

5. Steel columns, before their installation, should have washers tag welded at the inner part of the column at 42 inches (1100 mm) and 21 inches (550 mm) high to accommodate the erection of a wire rail system as soon as the steel floor deck is in place. In order to prevent sagging of the wire rail, U bolts could be tied to the wire rail besides the washers.

6. Materials should be stored away from floor and roof edges and holes in order to prevent falling object hazards.

7. Loading zones on the floor or roof edges (i.e., usually not protected by guardrail) should be guarded by other fall safety devices such as safety nets or fall arrest systems.
If the anchor point available is not able to withstand the 5400 pound requirement, a restrain or tethering system which stops the tied up worker from getting past the edge, could be used.

8. Before erecting a wood, pipe, or steel guardrail on a floor edge, the major components (posts, top rail and mid rail) of the guardrail should have already been assembled. This will reduce the exposure time of the workers erecting the guardrail.

9. For steel erection, whenever possible, the use of mobile scaffolding equipment (hydraulic lift baskets, scissors lifts) is recommended as a working platform during connection procedures. If this equipment is not available, ladders are a better option to climbing practices to reach the connection point. Further, seat lugs installed on the columns to support the beam during steel connection procedures can facilitate the process and reduce the risks associated with it. Finally, a fall arrest system using a combination of horizontal lifelines installed on the beams on the ground before lifting them in place and the wearing of two harnesses has proven effective (i.e., one harness is attached to the current beam’s lifeline. To move to a different beam, the worker attaches the second harness to a new lifeline and disconnects the first harness from the previous beam).

10. Scaffold structures which minimize the number of components to assemble and already have a prefabricated guardrail structure installed are more likely to prevent erection and installation problems. For example, a scaffolding structure where the guardrail is an essential part of the structural integrity of the structure forces the contractor to
install the guardrail in order to guarantee the structures vertical and lateral load bearing capacity.

11. Finally, the plan should emphasize the training required, availability of fall protection and personal protective equipment, and other safety policies that could affect fall safety performance.

The knowledge portrayed in the design and planning expert system module was also represented in the form of a decision structure which was later used to develop the knowledge base for this module, as discussed above.

The three expert system modules of SAFETY FIRST were tested and evaluated by independent experts and users. Through this evaluation, the performance of these modules has been rated between “good” and “very good.” From comments made by our experts and users, they see the major potential for immediate application of the investigation and evaluation modules as they stand now: these components could assist site management in investigating falls and assessing fall safety conditions in the site. As for the design and planning tool, the evaluators agree that there is a need to consider potential safety problems from the inception of the project; however, they are not sure the industry is ready to implement such practices. Designers may be especially reluctant to accept the burden of considering safety in their design practices; especially considering the fact that this burden is currently solely borne by the contractors. Further, there are legal considerations that may slow down this process.

As for the training module, as a consulting tool, experts agree that the system contains all the knowledge required to train workers and management in fall protection.
As a training tool, in addition to the knowledge accuracy, experts liked the testing facilities which give them an idea of the user's training knowledge, and the automatic record keeping facilities of the training sessions. They felt that this is a major advantage of this program. Finally, as an interactive training tool, experts felt the program was particularly useful to make trainees aware of the potential danger of operations in various construction platforms, to evaluate the adequacy of fall protection devices, and to understand the importance of safety in construction. The training program's knowledge and performance was also rated to be between "good" and "very good."

11.3 Recommendations

While the objective of building a tool to control falls in construction has been achieved, like any other computer program, continuous refinement and modification is needed in order to make it commercially applicable. As new technology in materials, erection methods, safety devices, and regulations emerge, the system will need to be enhanced and improved to incorporate them. Further, as computer technology improves, the system should be upgraded to incorporate these changes (e.g., digital video disk technology is just becoming prevalent in the market, allowing the storage of large amounts of data). Finally, future improvements of the program could be expanded to deal with some of the items listed on the scope and limitations of the study. The following are some recommendations for future studies or improvement of the SAFETY FIRST system:

1. This study limited its scope to the study of falls during vertical construction. Falls from electric poles, falls during bridge construction, and falls into trenches, though
significant, were not studied here. Further, in this research, we focused on one (i.e., form scaffolding) out of six major types of scaffolding structures. A natural extension of this research would be to use the same research methods used here to analyze fall accidents from all the components excluded here. This information could be easily incorporated into the computer program as add-on modules (this is one of the advantages of the structure used to develop the system, it allows for future extensions).

2. The methodology used to develop the SAFETY FIRST program which considers fall hazards and provides a tool to assist contractors during the early stages of the project (i.e., design and planning) and construction stages (i.e., investigate falls, evaluate fall safety, and train workers and management in fall protection) could be applied to control other construction accidents which cause a large portion of injuries and deaths (e.g., caught in between accidents).

3. As an investigation tool the system could be improved with more detailed knowledge about the enabling causes of falls related to the various components (i.e., worker and support components) included in the system. The fact that numerous variables often exist when a fall occurs may often limit the system to furnish the users with a general conclusion. This is particularly true when a user wishes to obtain a more specific cause (e.g., specific type of illness, structural strength of a safety device, etc.,) which is beyond the scope of this study. While these specific causes are important, our system requires other domains of knowledge (e.g., medical, psychology, structural...
engineering, etc.). This can certainly become an extension of SAFETY FIRST in the future.

4. As a training tool, while this system already incorporates multimedia features such as graphics, hypermedia and hypertext links, and video; it could be further improved by adding voice recognition and sound playing facilities to allow illiterate users (i.e., those who cannot read or write) to use the program. These facilities would be complemented by the use of touch screen sensors that eliminate the need of using the mouse.

5. Another factor the construction industry is currently facing is the inflow of workers whose main language is not English. For these workers, their English reading and writing skills are very limited. Even in Ohio, which does not have a large Spanish speaking population, one of the experts who tested the training system reported having the problem of training Spanish speaking workers. Therefore, there is a need to develop programs which incorporate bilingual knowledge.

6. Further, the video clips currently incorporated into the system are only used to illustrate the system's potential. In order to distribute the program, an agreement should be reached with one of the companies producing these training videos. Better yet, a future research project could be dedicated to capture the construction process in order to illustrate the dangers and factors involved in fall accidents.

7. In order to increase the availability and use of the system throughout the industry, the system should be available in channels where contractors, regardless of their size, can access it. Currently, the internet use is becoming more widespread, providing and
environment where the system could be globally available. Further, the internet now provides mechanisms to distribute the program which range from simple File Transfer Protocol (FTP) downloading facilities to application languages, such as Java or Common Gateway Interface (CGI). The main difference between Java and CGI languages is in that Java applications the code is downloaded and executed in the client’s computer, while CGI applications execute the program on a server computer.

8. Finally, a major test of any computer program is to deliver it to the final user and use it on a regular basis. All of the modules in the SAFETY FIRST program should be further field tested to determine if they can impact the fall safety record of contractors using it. A potential future study should involve distributing the program and studying its impact on the user’s safety results. One of the experts testing this program suggested the distribution of the program during one of the fall safety workshops given by the Bureau of Workers Compensation. These workshops are aimed at educating contractor’s site and safety managers. The expert suggested the distribution of the program in exchange for their input regarding the impact of the program in their sites.
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APPENDIX A

NAME AND BACKGROUND OF THE EXPERTS

The following are the experts (listed alphabetically) who agreed to provide their expert for the development of the SAFETY FIRST decision support system:

- Mr. Dan Feeney. Safety consultant on the safety & hygiene division of the Ohio Bureau of Workers' Compensation. He has about 10 years of experience in the construction industry being involved both as a layman in the site, and lately as a consultant for BWC.

- Dr. Fabian C. Hadipriono. The principal investigator for this project has been working in the construction area for almost 30 years and published over 150 safety and simulation related papers. He is also a member of the Architecture and Engineering Performance Information Center (AEPIC) research center at the University of Maryland, which is involved with worldwide accident cases. Furthermore, Dr. Hadipriono has been working closely for the last eight years with safety experts at SOCOTEC (the world’s largest private company for safety and performance control) in Paris, France.

- Dr. Richard E. Larew. A professor in the Construction Engineering and Management department at the Ohio State University. He is a renowned expert in construction accidents and has been working as a forensic engineer for over 40 years.

- Mr. Greg Mather, ALCM. Safety consultant on the safety & hygiene division of the Ohio BWC. He has about three years of experience in the construction industry working on construction sites as a layman and safety consultant.

- Mr. John Sahayda. Director on the industrial safety division of OSHA, Columbus, OH. He is a recognized expert on the area of safety whose experience working for OSHA, and before that, for the Ohio State University as a teacher have proven very important in facilitating the knowledge acquisition process.

- Mr. Mike G. Ypsilantis. Assistant area director of OSHA, Columbus, OH. He has a vast experience in the area of construction safety. Since 1966, he has worked as a safety engineer for an insurance company (i.e., investigating fall accidents), as a safety engineer during the construction of the Sears tower in Chicago, and as an Occupational Safety and Health Administration (OSHA) officer investigating fatality accidents.

All of these experts are recognized professionals in the area of construction safety and we feel that their combined knowledge and experience should provide a good foundation upon which to build the knowledge representation structures needed for the SAFETY FIRST program.
APPENDIX B

FAULT TREE STRUCTURES
Figure B.1: Fault tree model for the “Worker Fall from a Floor Opening” event

To be continued
Figure B.1 (Continued)
Figure B.1 (Continued)
To be continued
To be continued
Figure B.2: Fault tree model for the "Worker Fall from a Roof" event

To be continued
Figure B.2 (Continued)
Figure B.2 (Continued)

To be continued
Figure B.2 (Continued)

To be continued
Figure B.2: Fault tree model for the “Worker Fall from a Floor Edge” event (cont’d)
Figure B.3: Fault tree model for the "Worker Fall from a Steel Beam" event
Figure B.3 (Continued)
Figure B.3 (Continued)
Figure B.3 (Continued)
Figure B.3 (Continued)
To be continued

Figure B.4: Fault tree model for the "Worker Fall from the Top of a Wall" event
Figure B.4 (Continued)
Figure B.4 (Continued)
Figure B.4 (Continued)

WORKER SUPPORT II

WALL ENABLING II

WALL IMPACT RELATED

WALL ENVIRONMENT CONDITION-SLIP

WALL HAZARDS

WALL HOLE

WALL ELEVATION CHANGES

WALL EXCESSIVE SLOPE

WALL OBSTACLES

WALL EQUIPMENT IMPACT

WALL MATERIAL IMPACT

WALL RAIN

WALL SNOW

WALL FRONT

WALL HAIL

WALL SMALL MATERIAL

WALL TOOL

WALL SLIPPERY SUBSLANDE
Figure B.5: Fault tree model for the "Worker Fall from a Wall Opening" event
To be continued
Figure B.5 (Continued)
To be continued
Figure B.5 (Continued)
Figure B.6: Fault tree for “Worker Fall from a Form Scaffold” event
Figure B.6 (Continued)

To be continued
Figure B 6 (Continued)
Figure B.6 (Continued)
To be continued
Figure B.7: Fault tree model for the "Worker Fall from a Portable Ladder" event
Figure B.7 (Continued)
To be continued
To be continued
Figure B.7 (Continued)

- Worker Support
  - G42
    - Ladder Enables
      - G53
        - Ladder Broken Steps
        - Ladder Obstacles
        - Ladder Hole On Step
    - Ladder Dropping
      - G56
        - Ladder Impact Related
        - Ladder Environment Condition Slip
    - Ladder Hazards
      - G64
        - Ladder Equipment Impact
        - Ladder Material Impact
        - Ladder Rain
        - Ladder Snow
        - Ladder Frost
        - Ladder Hail
        - Ladder Small Material
        - Ladder Tool
        - Ladder Slippery Substance

- B616
- B617
- B618
- B714
- B715
- B716
- B717
- B718
- B719
- B720
- B721
- B722
Figure B.8: Fault tree model for the "Inadequate Guardrail System" event
Figure B.9: Fault Tree model for the “Inadequate Catch Platform” event
Figure B.11: Fault tree model for the “Inadequate Fall Arrest” event
Figure B.12: Fault tree model for the "Inadequate Warning Line" event
Figure B.13: Fault tree model for the "Inadequate CAZ" event
Figure B.14: Fault tree model for the "Inadequate Cover" event
APPENDIX C

DECISION STRUCTURES FOR INVESTIGATION EXPERT SYSTEM
Figure C.1: Decision Structure for Worker Fall from a Roof Investigation

To be continued
Figure C.1 (Continued)

```
Roof Exposed to Weather?
   /\  \
  Y   N
  / \  / \
 Weather Gust Conditions?  Weather Hail Conditions?
  Y   N    Y   N
  /     /    /     /
 Gust Impact?  Hail Impact?  Worker Slip with Water, Ice on Floor?
     Y   N        Y   N
     / \        / \  \
 1  RoBas 21   RoBas 22  RoBas 23  RoBas 24
```

```
Worker Extrctnely Hot Conditions?  Worker Slip?
   /\  \
  Y   N
  / \  / \
 Weather Rain, Snow, Hail Conditions?  Worker Collapse due to Dehydration?
  Y   N    Y   N
  /     /    /     /
 Worker Extrctnely Hot Conditions?  Worker Collapse due to Dehydration?
     Y   N        Y   N
     / \        /     \
 1  RoBas 25   RoBas 26  RoBas 27
```

Small materials (e.g., gravel) on Roof?
   /\  \
  Y   N
  / \  /
 Worker Extrctnely Hot Conditions?  Worker Extrctnely Hot Conditions?
     Y   N        Y   N
     /     \
 1  RoBas 25   RoBas 26  RoBas 27
```

To be continued
Figure C.1 (Continued)

Equipment Moving Material above Roof?
  Y  No  Yes
  Y  Other Workers on Roof?
  N  No  Yes
     Y  Avoiding Material Impact?
     N  N  Yes
        Y  Worker Wearing Hard Hat
        N  No  Yes
           Y  Worker Provided with Hard Hat?
           N  Contact with Power Source?
           Y  RoBas 15
           N  RoBas 16
  N  To be continued

Overhead Protection?
  Y  RoBas 13
  N  RoBas 14
     Y  Impact on Head?
     N  RoBas 17
        Y  Worker who fell Outside his/her Work Area?
        N  RoBas 18
           Y  RoBas 19
           N  RoBas 20

Other Worker Impact with Tool or Material?
  Y  RoBas 17
  N  RoBas 18

490
Figure C.1 (Continued)
Figure C.1 (Continued)

Tools or Materials on the Roof?
- Y: Worker Trip?
  - Y: Specific Areas on Floor to Store Tools and Place Materials?
    - Y: RoBas 38
    - N: RoBas 39
  - N: RoBas 40

Chronic Health Problem?
- Y: Worker Collapse due to Chronic Problem?
  - Y: RoBas 41
  - N: RoBas 40

Acute Health Problem?
- Y: Worker Collapse due to Acute Problem?
  - Y: RoBas 42
  - N: RoBas 41

History of Alcohol Related Problems?
- Y: Worker Drinking before or during Work?
  - Y: RoBas 43
  - N: RoBas 42

History of Drug Abuse Problems?
- Y: Worker using Drugs before or during Work?
  - Y: RoBas 44
  - N: RoBas 43

To be continued
Figure C.1 (Continued)

Worker Taking Prescription or Over the Counter Medicine?

Worker Collapse due to Side Effects (e.g., Drowsy)?

Worker Seem to notice Roof Edge or Skylight?

If Weather exposed and Rain, Snow, Hail, Fog. Poor Visibility?

If Weather Exposed and Rain, Snow, Hail, Extreme Heat, or Extreme Cold. Worker Distracted?

Worker Distracted by Occurrence on Surroundings?

Worker Distracted by Personal Problems (Stress)?

Worker Acting Recklessly at the Time of the Accident?

Worker Trained or Experienced

To be continued
Figure C.1 (Continued)

Worker did not seem to notice the hazard?

Roof Exposed to Weather Conditions?

If Rain, Snow, Hail, or Fog. Poor Visibility?

If Rain, Snow, Hail, Extreme Heat, or Extreme Cold. Worker Distracted?

Worker Distracted by Occurrence on Surroundings?

Worker Distracted by Personal Problems (Stress)?

Worker Trained or Experienced?

To be continued
Figure C.1  (Continued)

2

- Preliminary Conclusion

- Pitched Roof Fall?
  - Y
    - Fall Protection or Prevention Devices?
      - N
        - Cond 1
      - Y
        - Guardrail System Installed?
          - N
            - Final Conclusion
          - Y
            - Guardrail System Investigation
              - Figure C.10
              - Final Conclusion

- Catch Platform Installed?
  - Y
    - Catch Platform Investigation
      - Figure C.11

- Safety Net System Installed?
  - Y
    - Safety Net System Investigation
      - Figure C.12

- Fall Arrest System Installed?
  - Y
    - Fall Arrest System Investigation
      - Figure C.13
      - Final Conclusion

To be continued
Figure C.1 (Continued)

1. Flat Roof Fall?
   - Yes → Fall Protection or Prevention Devices?
   - No → Cond 1

2. Fall Protection or Prevention Devices?
   - Yes → Guardrail System Installed?
   - No → If none of previous devices installed, Warning Line Installed?

3. Guardrail System Installed?
   - Yes → Guardrail System Investigation
   - No → Final Conclusion

4. Catch Platform Installed?
   - Yes → Catch Platform Investigation
   - No → Final Conclusion

5. Safety Net System Installed?
   - Yes → Safety Net System Investigation
   - No → Final Conclusion

6. Fall Arrest System Installed?
   - Yes → Fall Arrest System Investigation
   - No → Final Conclusion

7. Warning Line Installed?
   - Yes → Warning Line Investigation
   - No → CAZ Installed?

8. Control Access Zone Investigation
   - Yes → Final Conclusion
   - No → Final Conclusion

To be continued
Figure C.2: Decision Structure for Worker Fall from Form Scaffold Investigation
Figure C.2 (Continued)

- **Other Workers on Scaffold?**
  - **Other Worker Impact?**
    - **Other Worker Impact with Tool or Material?**
      - **Both Workers Supposed to be on Floor?**
        - **Worker who fell Outside his/her Work Area?**
          - **F SBas 33**
        - **F SBas 32**
      - **FSBas 31**
    - **FSBas 34**
  - **FSBas 31**

- **Electric Power Source?**
  - **Contact with Power Source?**
    - **Weather Gust Conditions?**
      - **Weather Gust Impact?**
        - **FSBas 35**
    - **Weather Hail Conditions?**
      - **Weather Hail Impact?**
        - **FSBas 36**

To be continued
Figure C.2 (Continued)

- Weather Rain, Snow, Hail Conditions?
  - Worker Slip with Water, Ice on Floor?
    - Yes: FSBas 37
    - No: FSBas 37
  - No: FSBas 38

- Worker Extremely Hot Conditions?
  - Yes: FSBas 39
  - No: FSBas 39

- Worker Slip?
  - Yes: FSBas 40
  - No: FSBas 40

- Small materials (e.g., gravel) on Planks?
  - Yes: FSBas 39
  - No: FSBas 40

- Slippery Liquid Substances on Plank?
  - Yes: FSBas 40
  - No: FSBas 40

To be continued
Figure C.2 (Continued)

Sloped Surface?  
Y  
Worker Slip?  
Y  
FSBas 41

N  
Planks Overlapping?  
Y  
Worker Trip?  
Y  
FSBas 42

N  
Spacing between or Split Planks?  
Y  
Worker Trip?  
Y  
FSBas 43

N  
Tools or Materials on the Planks?  
Y  
Worker Trip?  
Y  
FSBas 44

N  
Worker Collapse due to Chronic Problem?  
Y  
FSBas 45

To be continued
Figure C.2 (Continued)

Acute Health Problem?

Worker Collapse due to Acute Problem?

History of Alcohol Related Problems?

Worker Drinking before or during Work?

Worker Collapse due to Alcohol Use?

Final Conclusion

History of Drug Abuse Problems?

Worker using Drugs before or during Work?

Worker Collapse due to Drug Use?

Worker Taking Prescription or Over the Counter Medicine?

Worker Collapse due to Side Effects (e.g., Drowsy)?

FSBas 46

FSBas 47

FSBas 48

FSBas 49

To be continued
Figure C.2 (Continued)
Figure C.3: Decision Structure for Worker Fall from Floor Opening Investigation

To be continued
Figure C.3 (Continued)

- **Floor Exposed to Weather?**
  - **Weather Gust Conditions?**
    - **Gust Impact?**
      - **FOBas 21**
  - **Weather Hail Conditions?**
    - **Hail Impact?**
      - **FOBas 22**
  - **Weather Rain, Snow, Hail Conditions?**
    - **Worker Slip with Water, Ice on Floor?**
      - **Barricades or Warning Signs Used?**
        - **FOBas 25**
  - **Worker Extremely Hot Conditions?**
    - **Worker Collapse due to Dehydration?**
      - **FOBas 23**
  - **Worker Slip?**
    - **Barricades or Warning Signs Used?**
      - **FOBas 27**

- **Small materials (e.g., gravel) on Floor?**
  - **Y**
  - **Worker Slip?**
    - **N**
  - **N**

To be continued
Figure C.3 (Continued)

Slippery Liquid Substances on Floor?

Excessively Sloped Floor?

Sudden Elevation Changes on Floor?

Openings on the Floor?

Objects Protruding on the Floor?

Worker Slip?

Worker Slip?

Worker Trip?

Worker Trip?

Worker Trip?

Worker Trip?

Barricades or Warning Signs used?

Barricades or Warning Signs used?

Barricades or Warning Signs used?

Barricades or Warning Signs used?

Barricades or Warning Signs used?

Barricades or Warning Signs used?

To be continued
Figure C.3 (Continued)

To be continued
Worker Taking Prescription or Over the Counter Medicine?

Worker Collapse due to Side Effects (e.g., Drowsy)?

FOBas 44

Y

N

Worker Seem to notice Floor Hole?

If Weather exposed and Rain, Snow, Hail, Fog, Poor Visibility?

FOBas 45

Y

N

If Weather Exposed and Rain, Snow, Hail, Extreme Heat, or Extreme Cold. Worker Distracted?

FOBas 46

Y

N

Worker Distracted by Occurrence on Surroundings?

FOBas 47

Y

N

Worker Distracted by Personal Problems (Stress)?

FOBas 48

Y

N

Worker Reckless Behavior Tendency?

Worker Acting Recklessly at the Time of the Accident?

FOBas 49

Y

N

Worker Trained or Experienced

Y

N

To be continued
Figure C.3  (Continued)

Worker did not seem to notice the hazard?

Floor Exposed to Weather Conditions?

If Rain, Snow, Hail, or Fog. Poor Visibility?

If Rain, Snow, Hail, Extreme Heat, or Extreme Cold. Worker Distracted?

Worker Distracted by Occurrence on Surroundings?

Worker Distracted by Personal Problems (Stress)?

Worker Trained or Experienced?

To be continued
Figure C.3 (Continued)

2

- Preliminary Conclusion

- Fall Protection or Prevention Devices?
  - Y: Hole Cover Installed?
    - Y: Guardrail System Installed?
      - Y: Safety Net System Installed?
        - Y: Fall Arrest System Installed?
          - Y: Final Conclusion
          - N: Fall Arrest System Investigation
            - Figure C.13
          - N: Safety Net System Investigation
            - Figure C.12
        - N: Safety Net System Installed?
          - Y: Fall Arrest System Installed?
            - Y: Final Conclusion
            - N: Fall Arrest System Investigation
              - Figure C.13
          - N: Fall Arrest System Installed?
            - Y: Final Conclusion
            - N: Fall Arrest System Investigation
              - Figure C.13
        - N: Fall Arrest System Installed?
          - Y: Final Conclusion
          - N: Fall Arrest System Investigation
            - Figure C.13
      - N: Guardrail System Investigation
        - Figure C.10
    - N: Cover Investigation
      - Figure C.16
  - N: Final Conclusion
- N: Cond 1

Final Conclusion
Figure C.4: Decision Structure for Worker Fall from Steel Beam Investigation

To be continued
Figure C.4 (Continued)

[Diagram of a decision tree or流程图, detailing various scenarios such as working surface above the beam, equipment moving above the beam, falling material impact, worker wearing a hard hat, etc., with yes (Y) and no (N) responses leading to different actions or conclusions, such as SBBas 11, SBBas 12, etc.]
Figure C.4 (Continued)
Figure C.4 (Continued)

Chronic Health Problem?

Acute Health Problem?

History of Alcohol Related Problems?

History of Drug Abuse Problems?

Worker Collapse due to Acute Problem?

Worker Collapse due to Chronic Problem?

Worker Drinking before or during Work?

Worker using Drugs before or during Work?

Worker Collapse due to Side Effects (e.g., Drowsy)?

Worker Taking Prescription or Over the Counter Medicine?

Worker using Drugs before or during Work?

Worker Drinking before or during Work?

Worker Collapse due to Alcohol Use?

Worker Collapse due to Drug Use?

To be continued
Figure C.4 (Continued)

1. Worker did not seem to notice the hazard?
   - Y: Beam Exposed to Weather Conditions?
     - Y: If Rain, Snow, Hail, or Fog, Poor Visibility?
       - Y: Worker Distracted by Occurrence on Surroundings?
         - Y: Worker Distracted by Personal Problems (Stress)?
           - Y: SBBas 38
           - N: SBBas 37
         - N: SBBas 36
       - N: Worker Distracted?
         - Y: SBBas 36
         - N: SBBas 35
     - N: If Rain, Snow, Hail, Extreme Heat, or Extreme Cold.
       - Worker Distracted?
         - Y: SBBas 36
         - N: SBBas 35
   - N: Worker Trained or Experienced?
     - Y: SBBas 39
     - N: SBBas 34

2. Worker Trained or Experienced?
   - Y: SBBas 39
   - N: SBBas 34

Worker Reckless Behavior Tendency?
- Y: Worker Acting Recklessly at the Time of the Accident?
  - Y: SBBas 33
  - N: Worker did not seem to notice the hazard?
- N: Worker Trained or Experienced?
  - Y: SBBas 34
  - N: SBBas 33

To be continued
Figure C.4 (Continued)

2

Preliminary Conclusion

Fall Protection or Prevention Devices? Y

N

Cond 1

Final Conclusion

Fall Arrest System Installed? Y

Fall Arrest System Investigation

Figure C.13

Safety Net System Installed? N

Safety Net System Investigation

Figure C.12

Y

Final Conclusion

N

N

Final Conclusion
Figure C.5: Decision Structure for Worker Fall from Wall Opening Investigation
Figure C.5 (Continued)

- Working Surface Above the Floor?
  - Y: Equipment Moving Material Above Floor?
    - Y: Falling Material Impact?
      - Y: Toeboards?
      - N: WOBas 13
      - Y: Overhead Protection?
      - Y: Impact on Head?
        - Y: Worker Wearing Hard Hat
          - Y: WOBas 1
          - N: Worker Provided with Hard Hat?
            - Y: WOBas 15
    - N: WOBas 16
- N: Equipment Moving Material Above Floor?
  - N: Other Workers on Floor?
    - Y: Other Worker Impact?
      - Y: Both Workers Supposed to be on Floor?
      - Y: Worker who fell Outside his/her Work Area?
        - Y: WOBas 17
        - N: WOBas 18
      - N: WOBas 19
    - N: N: Other Worker Impact with Tool or Material?
      - Y: Contact with Power Source?
        - Y: WOBas 20
      - N: N: Electric Power Source?
        - Y: WOBas 1
        - N: N: Electric Power Source?
          - Y: WOBas 1
          - N: N: Electric Power Source?
Figure C.5 (Continued)

Floor Exposed to Weather? Y N
Weather Gust Conditions? Y N
Gust Impact? Y N
WOBas 21

Weather Hail Conditions? Y N
Hail Impact? Y N
WOBas 22

Weather Rain, Snow, Hail Conditions? Y N
Worker Slip with Water, Ice on Floor? Y N
Barricades or Warning Signs Used? Y N
WOBas

Worker Extremely Hot Conditions? Y N
Worker Collapse due to Dehydration? Y N
WOBas 25

Small materials (e.g., gravel) on Floor? Y N
Worker Slip? Y N
Barricades or Warning Signs Used? Y N
WOBas

To be continued
Figure C.5 (Continued)

Slippery Liquid Substances on Floor?
  | N
  ↓
  Worker Slip?
  | Y
  ↓
  Barricades or Warning Signs used?
  | Y
  ↓
  WOBas
  | Y
  ↓
  WOBas

Excessively Sloped Floor?
  | Y
  ↓
  Worker Trip?
  | Y
  ↓
  WOBas

Sudden Elevation Changes on Floor?
  | Y
  ↓
  Worker Trip?
  | Y
  ↓
  WOBas

Openings on the Floor?
  | Y
  ↓
  Worker Trip?
  | Y
  ↓
  WOBas

Objects Protruding on the Floor?
  | Y
  ↓
  Worker Trip?
  | Y
  ↓
  WOBas

To be continued
Figure C.5 (Continued)

- Tools or Materials on the Floor?
  - No
    - Worker Trip?
      - No
        - Specific Areas on Floor to Store Tools and Place Materials?
          - No
            - WOBas 40
          - Yes
            - WOBas 41
      - Yes
        - Worker Collapse due to Acute Problem?
          - No
            - WOBas 42
          - Yes
            - History of Alcohol Related Problems?
              - No
                - Worker Drinking before or during Work?
                  - Yes
                    - Worker using Drugs before or during Work?
                      - Yes
                        - WOBas 43
                      - No
                        - WOBas 42
              - Yes
                - Worker Collapse due to Alcohol Use?
                  - Yes
                    - Worker Collapse due to Drug Use?
                      - Yes
                        - WOBas 43
                      - No
                        - Worker Collapse due to Acute Problem?
                          - Yes
                            - History of Drug Abuse Problems?
                              - Yes
                                - WOBas 43
                              - No
                                - WOBas 42
                          - No
                            - History of Alcohol Related Problems?
                              - Yes
                                - Worker Drinking before or during Work?
                                  - Yes
                                    - Worker using Drugs before or during Work?
                                      - Yes
                                        - WOBas 43
                                      - No
                                        - WOBas 42
                                    - No
                                      - WOBas 43
                                  - No
                                    - WOBas 42
                              - No
                                - WOBas 42
                          - No
                            - Worker Collapse due to Acute Problem?
                              - Yes
                                - History of Drug Abuse Problems?
                                  - Yes
                                    - WOBas 43
                                  - No
                                    - WOBas 42
                              - No
                                - WOBas 42
          - Yes
            - Worker Collapse due to Chronic Problem?
              - Yes
                - WOBas 43
              - No
                - Worker Trip?
                  - Yes
                    - Specific Areas on Floor to Store Tools and Place Materials?
                      - No
                        - WOBas 40
                      - Yes
                        - WOBas 41
                  - No
                    - Worker Trip?
                      - Yes
                        - Specific Areas on Floor to Store Tools and Place Materials?
                          - No
                            - WOBas 40
                          - Yes
                            - WOBas 41
                      - No
                        - Worker Trip?
                          - Yes
                            - Specific Areas on Floor to Store Tools and Place Materials?
                              - No
                                - WOBas 40
                              - Yes
                                - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
                                  - No
                                    - WOBas 40
                                  - Yes
                                    - WOBas 41
                          - No
                            - Worker Trip?
                              - Yes
                                - Specific Areas on Floor to Store Tools and Place Materials?
Figure C.5 (Continued)

Worker Taking Prescription or Over the Counter Medicine?

- Worker Collapse due to Side Effects (e.g., Drowsy)?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?

Worker Seem to notice the Wall Opening?

- N
- Y: If Weather exposed and Rain, Snow, Hail, Fog. Poor Visibility?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?

Worker Reckless Behavior Tendency?

- N
- Y: Worker Acting Recklessly at the Time of the Accident?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?

Worker Trained or Experienced

- N
- Y: Worker Taking Prescription or Over the Counter Medicine?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?
  - N
  - Y: Worker Taking Prescription or Over the Counter Medicine?

To be continued
Figure C.5 (Continued)

Worker did not seem to notice the hazard?

Floor Exposed to Weather Conditions?

If Rain, Snow, Hail, or Fog, Poor Visibility?

If Rain, Snow, Hail, Extreme Heat, or Extreme Cold, Worker Distracted?

Worker Distracted by Occurrence on Surroundings?

Worker Distracted by Personal Problems (Stress)?

Worker Trained or Experienced?

To be continued
Figure C.5  (Continued)

[Diagram showing flowchart with decision points for Fall Protection or Prevention Devices, Guardrail System, Safety Net System, and Fall Arrest System installation, leading to Final Conclusion.]
To be continued
Figure C.6 (Continued)

- Working Surface Above the Wall?
- Equipment Moving Material Above Wall?
  - Y: Falling Material Impact?
  - N: Avoiding Material Impact?
    - Y: Toeboards?
    - N: Overhead Protection?
      - Y: Impact on Head?
      - N: Worker Wearing Hard Hat
        - Y: Other Worker Impact?
        - N: Other Worker Impact with Tool or Material?
          - Y: Both Workers Supposed to be on Floor?
            - Y: Worker who fell Outside his/her Work Area?
              - Y: Contact with Power Source?
              - N: TWBas 18
          - N: TWBas 12
        - N: TWBas 11
    - N: Work Provided with Hard Hat?
      - Y: TWBas 13
      - N: TWBas 14
  - N: Other Workers on Wall?
    - Y: Other Worker Impact?
    - N: Other Worker Impact with Tool or Material?
      - Y: Both Workers Supposed to be on Floor?
      - Y: Worker who fell Outside his/her Work Area?
        - Y: Contact with Power Source?
        - N: TWBas 18
      - N: TWBas 15
    - N: TWBas 11
Figure C.6 (Continued)

Wall Exposed to Weather?

- Weather Gust Conditions?
  - Gust Impact? (Y: TWBas 19, N: TWBas 20)
  - Gains

- Weather Hail Conditions?
  - Hail Impact? (Y: TWBas 21, N: TWBas 22)

- Weather Rain, Snow, Hail Conditions?
  - Worker Slip with Water, Ice on Wall? (Y: TWBas 23, N: TWBas 24)

- Worker Extremely Hot Conditions?
  - Worker Collapse due to Dehydration? (Y: TWBas 24, N: TWBas 25)

Small materials (e.g., gravel) on Wall?

Worker Slip? (Y: TWBas 26, N: TWBas 27)

To be continued
Figure C.6 (Continued)

Chronic Health Problem?

Worker Collapse due to Chronic Problem?

TWBas 29

2

Acute Health Problem?

Worker Collapse due to Acute Problem?

TWBas 30

2

History of Alcohol Related Problems?

Worker Drinking before or during Work?

TWBas 31

2

History of Drug Abuse Problems?

Worker using Drugs before or during Work?

TWBas 32

2

Worker Collapse due to Side Effects (e.g., Drowsy)?

Worker Taking Prescription or Over the Counter Medicine?

TWBas 34

2

To be continued
Figure C.6 (Continued)

Worker Reckless Behavior Tendency?
Y
Worker Acting Recklessly at the Time of the Accident?
Y
Worker Trained or Experienced

Worker did not seem to notice the hazard?
Y
Wall Exposed to Weather Conditions?
Y
If Rain, Snow, Hail, or Fog, Poor Visibility?
Y
If Rain, Snow, Hail, Extreme Heat, or Extreme Cold, Worker Distracted?
Y
Worker Distracted by Occurrence on Surroundings?
Y
Worker Distracted by Personal Problems (Stress)?

To be continued
Figure C.7: Decision Structure for Worker Fall from Ladder Investigation
Figure C.7 (Continued)
Figure C.7 (Continued)

Equipment on Floor around Ladder?  
  
  Working Surface Above the Floor?  
  
  Equipment Moving Material Above Floor?  
  
  Equipment Impact?  
  
  Avoiding Equip. Impact?  
  
  Equipment Enabling Cause?  
  
  Equipment Triggering Cause?  
  
  Equipment Operator Cause?  
  
  Avoiding Equipment Falling Material Avoiding Material Impact?  
  
  Toeboards?  
  
  Overhead Protection?  
  
  Impact on Head?  
  
  Worker Wearing Hard Hat  
  
  Worker Provided with Hard Hat?  
  
  To be continued
Other Workers on Ladder Surroundings? N
  Y
  Other Worker Impact? N
  Y
  Other Worker Impact with Tool or Material? N
  Y
  Both Workers Supposed to be on Floor? N
  Y
  Worker who fell Outside his/her Work Area? N
  Y
  PLB34
  PLB33
  PLB32
  PLB35

Electric Power Source? N
  Y
  Contact with Power Source? N
  Y
  PLB35

Exposed to Weather? N
  Y
  Weather Gust Conditions? N
  Y
  Gust Impact? N
  Y
  PLB36

Weather Hail Conditions? N
  Y
  Hail Impact? N
  Y
  PLB37

To be continued
Figure C.7 (Continued)
Final Conclusion

Worker Trip?

Worker Slip?

Excessively Smooth Steps?

Broken or Split Steps?

Tools or Materials on the Steps?

Chronic Health Problem?

Worker Collapse due to Chronic Problem?

PLBas 42

PLBas 43

PLBas 44

PLBas 45

Final Conclusion

To be continued
Figure C.7 (Continued)

Acute Health Problem?  
Y  
Worker Collapse due to Acute Problem?  
N  
   Y  
   PLBas 46  
   Final Conclusion  
   N  

History of Alcohol Related Problems?  
Y  
Worker Drinking before or during Work?  
N  
   Y  
   Worker Collapse due to Alcohol Use?  
N  
       Y  
       PLBas 47  
       Final Conclusion  
       N  

History of Drug Abuse Problems?  
Y  
Worker using Drugs before or during Work?  
N  
   Y  
   Worker Collapse due to Drug Use?  
N  
       Y  
       PLBas 48  
       Final Conclusion  
       N  

Worker Taking Prescription or Over the Counter Medicine?  
Y  
Worker Collapse due to Side Effects (e.g., Drowsy)?  
N  
   Y  
   PLBas 49  
   Final Conclusion  
   N  

To be continued
Worker Reckless Behavior Tendency?
  Y → Worker Acting Recklessly at the Time of the Accident?
  Y → PLBas 50
  N → Worker Trained or Experienced
      Y → PLBas 51
      N → Final Conclusion

Worker did not seem to notice the hazard?
  Y → Exposed to Weather Conditions?
  Y → If Rain, Snow, Hail, or Fog. Poor Visibility?
      Y → PLBas 52
      N → PLBas 53
  N → Worker Distracted by Occurrence on Surroundings?
      Y → PLBas 54
      N → Final Conclusion

Worker Distracted by Personal Problems (Stress)?
  Y → PLBas 55
  N → Final Conclusion

Worker Trained or Experienced?
  Y → Final Conclusion
  N → PLBas 56
Figure C.8: Decision Structure for Worker Fall from Same Level Investigation
Figure C.8 (Continued)

Other Workers on Floor? 

Y → Other Worker Impact? 

N → Other Worker Impact with Tool or Material? 

Y → Both Workers Supposed to be on Floor? 

N → Worker who fell Outside his/her Work Area? 

Y → SLBas 13 

N → SLBas 12 

Y → SLBas 11

N → SLBas 14 

Y → Contact with Power Source? 

N → Floor Exposed to Weather? 

Y → Weather Gust Conditions? 

N → Weather Hail Conditions? 

Y → Gust Impact? 

N → Hail Impact? 

Y → SLBas 15 

N → SLBas 16 

To be continued
Figure C.8  (Continued)
Figure C.8 (Continued)

Sudden Elevation Changes on Floor?

- Yes: Worker Trip?
  - Yes: Barricades or Warning Signs used?
    - Yes: SLBas 26
    - No: SLBas 27
  - No: SLBas 26

- No: SLBas 27

Openings on the Floor?

- Yes: Worker Trip?
  - Yes: Barricades or Warning Signs used?
    - Yes: SLBas 28
    - No: SLBas 29
  - No: SLBas 28

- No: SLBas 29

Objects Protruding on the Floor?

- Yes: Worker Trip?
  - Yes: Barricades or Warning Signs used?
    - Yes: SLBas 30
    - No: SLBas 31
  - No: SLBas 30

- No: SLBas 31

Tools or Materials on the Floor?

- Yes: Worker Trip?
  - Yes: Barricades or Warning Signs used?
    - Yes: SLBas 32
    - No: SLBas 33
  - No: SLBas 32

- No: SLBas 33

Chronic Health Problem?

- Yes: Worker Collapse due to Chronic Problem?
  - Yes: SLBas 34
  - No: SLBas 34

Specific Areas on Floor to Store Tools and Place Materials?

- Yes: Worker Trip?
  - Yes: Barricades or Warning Signs used?
    - Yes: SLBas
    - No: SLBas
  - No: SLBas

- No: SLBas

Final Conclusion

To be continued
Figure C.8 (Continued)

Acute Health Problem?  
Y  
Worker Collapse due to Acute Problem?  
Y  
SLBas 35  
N  
Final Conclusion

N  
History of Alcohol Related Problems?  
Y  
Worker Drinking before or during Work?  
Y  
Worker Collapse due to Alcohol Use?  
Y  
SLBas 36  
N  
Final Conclusion

History of Drug Abuse Problems?  
Y  
Worker using Drugs before or during Work?  
Y  
Worker Collapse due to Drug Use?  
Y  
SLBas 37  
N  
Final Conclusion

N  
Worker Taking Prescription or Over the Counter Medicine?  
Y  
Worker Collapse due to Side Effects (e.g., Drowsy)?  
Y  
SLBas 38  
N  
Final Conclusion

To be continued
Figure C.8 (Continued)

Worker Reckless Behavior Tendency?  
Y  
Worker Acting Recklessly at the Time of the Accident?  
Y  
SLBas 39  
Worker Trained or Experienced  
Y  N  
SLBas 40  
Final Conclusion  
Y  
Worker did not seem to notice the hazard?  
Y  
Floor Exposed to Weather Conditions?  
Y  
If Rain, Snow, Hail, or Fog, Poor Visibility?  
Y  N  
SLBas 41  
If Rain, Snow, Hail, Extreme Heat, or Extreme Cold, Worker Distracted?  
Y  N  
SLBas 42  
Worker Distracted by Occurrence on Surroundings?  
Y  N  
SLBas 43  
Worker Distracted by Personal Problems (Stress)?  
Y  N  
SLBas 44  
Worker Trained or Experienced?  
Y  N  
SLBas 45  
Final Conclusion
To be continued

Figure C.9: Decision Structure for Worker Slip Investigation
Figure C.9  (Continued)

History of Alcohol Related Problems?  
Y  N
Worker Drinking before or during Work?  
Y  N
SliBas 9  SliBas 10

History of Drug Abuse Problems?  
Y  N
Worker using Drugs before or during Work?  
Y  N
Drug Side Effects include Drowsiness?  
Y  N
SliBas 11

Worker Taking Prescription or Over the Counter Medicine?  
Y  N
SliBas 12

Chronic Health Problem?  
Y  N
SliBas 13

Acute Health Problem?  
Y  N

To be continued
Worker did not seem to notice the hazard?

Y

Floor Exposed to Weather Conditions?

Y

If Rain, Snow, Hail, or Fog. Poor Visibility?

Y

SliBas 14

N

If Rain, Snow, Hail, Extreme Heat, or Extreme Cold. Worker Distracted?

Y

SliBas 15

N

Worker Distracted by Occurrence on Surroundings?

Y

SliBas 16

N

Worker Distracted by Personal Problems (Stress)?

Y

SliBas 17

N

Worker Trained or Experienced?

Y

SliBas 18

N

Final Conclusion
Figure C.10: Decision Structure for Guardrail System Investigation
Figure C.10 (Continued)

Guardrail Posts Failure?  

- Wood?  
  - Yes: Table 5.7  
  - No:  
    - Pipe?  
      - Yes: Table 5.8  
      - No:  
        - Str. Steel?  
          - Yes: Table 5.9  
          - No: Other?  
            - Cond 26  
            - Y: C. Cause?  
              - Yes: Cond 27  
              - No: Cond 28  
            - N:  

- Other?  
  - Cond 26  

Guardrail Toeboard Failure?  

- Adequate Strength?  
  - Yes:  
    - Toeboard Wear?  
      - Yes: Cond 30  
      - No: Adequate Bracing?  
        - Yes: Cond 32  
        - No: Cond 31  
  - No: Cond 29  

Rail/Post Connection Failure?  

- Inadequate Connection?  
  - Yes: Cond 33  
  - No: Cond 34  

To be continued
Figure C.10  (Continued)

To be continued
Figure C.10 (Continued)

- If topple over TR and fall below TR are DK?
  - Y: Guardrail Component Missing? (Table 5.11)
  - N: Guardrail Rails Elevations? (Table 5.10)
  - N: C. Cause?

- If WireRail Temporarily Removed?
  - Y: Cond 50
  - N: Fall from Loading Zone?

- Worker Doing Job in Zone?
  - Y: Method to Control Access to Zone?
    - N: Cond 52
    - Y: Other Protection Fall Arrest?
      - N: Other Protection Safety Net?
        - N: Cond 53
      - Y: Cond 51
Figure C.11: Decision Structure for Catch Platform Investigation
Figure C.11 (Continued)

CP Guardrail System Installed?

Guardrail Top Rail Failure?

Wood?

Pipe?

Str. Steel?

Other?

Guardrail Mid Rail Failure?

Wood?

Pipe?

Str. Steel?

Other?

Guardrail Posts Failure?

Wood?

Pipe?

Str. Steel?

Other?

To be continued
Figure C.11 (Continued)
Figure C.12: Decision Structure for Safety Net Investigation
Figure C.12 (Continued)
Figure C.13: Decision Structure for Fall Arrest System Investigation
Figure C.13 (Continued)
Figure C.13 (Continued)

Failing Component. Harness?

- Yes (Y)
  - Yes (Y)
    - Harness Adequate Strength?
      - Yes (Y)
        -Harness Wear or Fatigue?
          - Yes (Y)
            - Cond 128
          - No (N)
            - Cond 127
      - No (N)
        - Cond 126
  - No (N)
    - Cond 128

- No (N)
  - Cond 129

Safety Belt Used?

- Yes (Y)
  - Cond 129
- No (N)
  - Worker Injury?
    - Yes (Y)
      - Falling Distance Larger than 6 ft.?
        - Yes (Y)
          - Cond 130
        - No (N)
          - Worker Impact with Lower Structure?
            - Yes (Y)
              - Cond 131
            - No (N)
              - Worker Impact with Lower Side Structure?
                - Yes (Y)
                  - Cond 132
              - No (N)

To be continued
Figure C.13 (Continued)

Horizontal lifeline and Lanyard?

Failing Component. Anchorage?

Anchorage Adequate Strength?

Anchorage Wear or Fatigue?

Cond 133

Cond 134

Cond 135

Cond 136

Cond 137

Cond 138

Cond 139

Cond 140

Cond 141

Cond 142

To be continued
Figure C.13 (Continued)
Figure C.13 (Continued)

Safety Belt Used?  Worker Injury?

Cond 155  Cond 156

Falling Distance Larger than 6 ft.?

Cond 157  Cond 158

Worker Impact with Lower Structure?

Self-retracting Line?

Failing Component. Anchorage?

Cond 159

Anchorage Adequate Strength?

Cond 160

Anchorage Wear or Fatigue?

Cond 161

To be continued
Failing Component. Lifeline?

- Y: More than One Worker Attached?
  - N: Lifeline Adequate Strength?
    - Y: Lifeline Wear or Fatigue?
      - Y: Cond 164
      - N: Cond 165
    - N: Cond 163
  - N: Cond 162
- N: Cond 166

Failing Component. Snaphook?

- Y: Snaphook Adequate Strength?
  - N: Cond 167
  - Y: Snaphook Wear or Fatigue?
    - Y: Cond 168
    - N: Cond 166
- N: Cond 166

Failing Component. Deering or Connector?

- Y: D or C Adequate Strength?
  - N: Cond 169
  - Y: D or C Wear or Fatigue?
    - N: Cond 167
    - Y: Cond 167
- N: Cond 169

To be continued
Figure C.13 (Continued)

Failing Component, Harness?

- Y → Harness Adequate Strength?
- N → Harness Wear or Fatigue?

Harness Adequate Strength?

- Y → Worker Injury?
- N → Cond 172

Cond 172

Cond 175

Safety Belt Used?

- Y → Worker Injury?
- N → Falling Distance Larger than 6 ft.?

Falling Distance Larger than 6 ft.?

- Y → Cond 176
- N → Worker Impact with Lower Structure?

Worker Impact with Lower Structure?

- Y → Cond 177
- N → Worker Impact with Lower Side Structure?

Worker Impact with Lower Side Structure?

- Y → Cond 178
- N → Cond 173
Figure C.14: Decision Structure for Warning Line System Investigation
Figure C.14 (Continued)

CAZ Height is too High?

Worker Walked Under the Line?

CAZ Unprotected Area?

Safety Monitoring?

Monitor Failed to Warn Worker?

Monitor had Other Functions?

Monitor within Range?

Worker Failed to Comply with Warning?

Range?

To be continued
Figure C.15: Decision Structure for CAZ Investigation
Figure C.15 (Continued)

- CAZ Height is too High?
  - Yes, go to Cond 208
  - No, go to Cond 209
- Worker Walked Under the Line?
  - Yes, go to Cond 208
  - No, go to Cond 209
- CAZ Unprotected Area?
  - Yes, go to Cond 209
  - No, go to Cond 210
- Safety Monitoring?
  - Yes, go to Cond 210
  - No, go to Monitor Failed to Warn Worker?
    - Yes, go to Monitor Functions
      - Yes, go to Cond 213
      - No, go to Cond 214
    - No, go to Monitor within Range?
      - Yes, go to Cond 211
      - No, go to Cond 212
- Monitor Failed to Warn Worker?
  - Yes, go to Monitor Functions
    - Yes, go to Cond 213
    - No, go to Cond 214
  - No, go to Monitor within Range?
    - Yes, go to Cond 211
    - No, go to Cond 212
<table>
<thead>
<tr>
<th>Equipment Operating on Surface</th>
<th>Distance from Edge to Line</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>6 ft (1.8 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>6 ft (1.8 m)</td>
<td>Prob 95</td>
</tr>
<tr>
<td>No</td>
<td>6 ft (1.8 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>Yes</td>
<td>10 ft (3 m)</td>
<td>o.k.</td>
</tr>
<tr>
<td>Yes</td>
<td>10 ft (3 m)</td>
<td>Prob 96</td>
</tr>
<tr>
<td>Yes</td>
<td>10 ft (3 m)</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.1: Decision table for warning line edge distance

<table>
<thead>
<tr>
<th>Adequate Warning Line Installation</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 97</td>
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<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.2: Decision table for warning line installation

<table>
<thead>
<tr>
<th>Warning Line Elevations</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too high</td>
<td>Prob 98</td>
</tr>
<tr>
<td>Too low</td>
<td>Prob 99</td>
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<tr>
<td>Adequate</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.3: Decision table for warning line elevations

<table>
<thead>
<tr>
<th>Warning Line Strength is Adequate</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
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<tr>
<td>No</td>
<td>Prob 100</td>
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<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.4: Decision table for warning line strength

577
<table>
<thead>
<tr>
<th>Warning Line Wear or Fatigue</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Prob 101</td>
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<tr>
<td>No</td>
<td>o.k.</td>
</tr>
<tr>
<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.5: Decision table for warning line wear

<table>
<thead>
<tr>
<th>Adequate Cover Size</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
</tr>
<tr>
<td>No</td>
<td>Prob 102</td>
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<td>Don’t know</td>
<td>o.k.</td>
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</table>

Table D.6: Decision table for cover size

<table>
<thead>
<tr>
<th>Cover Adequately Secured</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>o.k.</td>
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<tr>
<td>No</td>
<td>Prob 103</td>
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<td>Don’t know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.7: Decision table for cover secured

<table>
<thead>
<tr>
<th>Cover Labelled</th>
<th>Conclusion</th>
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<tbody>
<tr>
<td>Yes</td>
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<tr>
<td>No</td>
<td>Prob 104</td>
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<td>o.k.</td>
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</table>

Table D.8: Decision table for cover labeled
<table>
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<tr>
<th>Cover Adequate Strength</th>
<th>Conclusion</th>
</tr>
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<tbody>
<tr>
<td>Yes</td>
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<td>No</td>
<td>Prob 105</td>
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<tr>
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<td>o.k.</td>
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</tbody>
</table>

Table D.9: Decision table for cover adequate strength

<table>
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<tr>
<th>Cover Wear or Fatigue</th>
<th>Conclusion</th>
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</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Prob106</td>
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<tr>
<td>No</td>
<td>o.k.</td>
</tr>
<tr>
<td>Don't know</td>
<td>o.k.</td>
</tr>
</tbody>
</table>

Table D.10: Decision table for cover wear
Figure D.1: Decision Structure for Worker Fall from the Roof Evaluation
Elevated Component is Roof Skylight

Fall Protection Devices Installed?  
N  Prob 1
Y

Guardrail System Installed?  
N
Fall Arrest System Installed?  
Y  Figure D.7
Y  Figure D.10

Safety Net System Installed?  
N
Other Device Installed?  
Y  Figure D.9
Y  Final Conclusion
N

Guardrail Rails Elevations?  
Table 6.67

Guardrail Posts Spacing?  
Table 6.68
Figure D.2: Decision Structure for Worker Fall from Form Scaffold Evaluation
Figure D.3: Decision Structure for Worker Fall from Floor Opening Evaluation
Figure D.4: Decision Structure for Worker Fall from Steel Beam Evaluation
Figure D.5: Decision Structure for Worker Fall from Wall Opening Evaluation
Figure D.6: Decision Structure for Worker Fall from Top Of Wall Evaluation
Guardrail System Installed? Y

Guardrail Component Missing? D. Table 6.2

Guardrail Rails Elevations? Table 6.2

Guardrail Posts Spacing? Table 6.3

Guardrail Rail Materials?

Wood? Y Tables 6.4 & 5

Pipe? Y Table 6.6

Str. Steel? Y Table 6.7

Wire Rope? Y Prob 15

Steel Plastic Bands? Y

Other? Table 6.8

To be continued

Figure D.7: Decision Structure for Guardrail System Evaluation
Figure D.7 (Continued)

Guardrail Posts
Materials?

Wood? Y Table 6.9
N

Pipe? Y D. Table 6.20
N

Str. Steel? Y D. Table 6.21
N

Other? D. Table 6.22

Rails Adequately
Secured to Posts?
D. Table 6.23

Posts Adequately
Secured to Floor?
D. Table 6.24

Guardrail System
Materials Wear?
D. Table 6.25
Figure D.8: Decision Structure for Catch Platform Evaluation
Figure D.8 (Continued)

CP Guardrail Rail Materials?
- Wood? Y → Table 6.25 & 26
  - N
- Pipe? Y → Table 6.27
  - N
- Str. Steel? Y → Table 6.28
  - N
- Other? Table 6.29

CP Guardrail Posts Materials?
- Wood? Y → Table 6.30
  - N
- Pipe? Y → Table 6.31
  - N
- Str. Steel? Y → Table 6.32
  - N
- Other? Table 6.33

CPG Rails Adequately Secured to Posts?
- Table 6.34

CPG Posts Adequately Secured to Platform?
- Table 6.35

CP Guardrail System Materials Wear?
- Table 6.36
Figure D.9: Decision Structure for Safety Net Evaluation
Fall Arrest System Installed?

-vertical Lifeline and Lanyard?

- Distance to Ground? Falling Distance?
  - Table 6.37

-vertical Lifeline and Lanyard?

- Locking Snaphooks?
  - Table 6.41

- Anchorage Point Strength?
  - Table 6.38

- Horizontal Lifeline?

- Distance to Ground? Falling Distance?
  - Table 6.41

- Arrest Force? Deceleration Distance?
  - Table 6.37

- Horizontal Line Installation?
  - Table 6.44

- Wear and Fatigue?
  - Table 6.43

- Deerings and Snaphooks Strength?
  - Table 6.40

- Self-Retracting Line?

- Free Falling Distance Allowed?
  - Table 6.46

- Arrest Force? Deceleration Distance?
  - Table 6.42

- Horizontal Lifeline Locking Snaphooks?
  - Table 6.45

- Lifeline Strength?

Figure D.10: Decision Structure for Fall Arrest Evaluation
Figure D.11: Decision Structure for Fall Arrest Evaluation
Figure D.13: Decision Structure for Warning Line System Evaluation
Figure D.13: Decision Structure for Cover Evaluation
APPENDIX E

TRAINING SYSTEM EVALUATION FORM
SAFETY FIRST TRAINING EVALUATION FORM

Evaluator: ....................................................................................................................................
Affiliation: ...................................................................................................................................
Position: ....................................................................................................................................... 

Purpose: The objective of this form is to evaluate the individual components and overall structure of the SAFETY FIRST training program. This form will ask you to evaluate the knowledge in the system and the various features on it. The information compiled will be used to make relevant changes to improve the system.

Preliminary Test

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rating</th>
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<tbody>
<tr>
<td></td>
<td>Very Good</td>
</tr>
</tbody>
</table>

Format

Questions and Answers

Relevance of Q/A

Feedback

User Interface:

Color Usage

Screen Layout

Format: The test format (i.e., multiple choice) is clear and consistent throughout the module.

Questions and Answers: The questions and Answers given by the system were clear and understandable. It is clear how to answer the questions. The potential answers are clear.

Relevance of Q/A: The questions and answers in the test are related to the fall protection topic.

Feedback: The system provides the user feedback as to his or her test performance and the correct answers to the given questions.

Color Usage: The colors used are easy to read and consistent throughout the module.

Screen Layout: The screen layout is clear and consistent throughout the module.

Comments:

..............................................................................................................................................
..............................................................................................................................................
..............................................................................................................................................
..............................................................................................................................................
Main Lessons

Fall Safety Knowledge:

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<tr>
<th>Criteria</th>
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<th>Good</th>
<th>Fair</th>
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<th>Very Poor</th>
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<td>Clarity</td>
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</table>

**Thoroughness:** All the fall protection knowledge required is included.

**Accuracy:** All the knowledge included is correct (i.e., truthful)

**Sequence and Organization:** The knowledge is adequately grouped and organized into lessons.

**Clarity:** The knowledge presented is clear (i.e., easy to understand).

Comments:

Lesson User Interface:

<table>
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<tr>
<th>Criteria</th>
<th>Rating</th>
<th>Very Good</th>
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**Color Usage:** The colors used are easy to read and consistent throughout the module.

**Screen Layout:** The screen layout is clear and consistent throughout the module.

**Amount of Information:** The information presented on each display is adequate (i.e., not too crowded and not too slight).

**Readability:** The text on the display is easy to read.

**Use of Graphics:** The graphics used are clear and pertinent to the topic.
Lesson Tests:

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Format: The test format (i.e., multiple choice) is clear and consistent throughout the module.
Questions and Answers: The questions and Answers given by the system were clear and understandable. It is clear how to answer the questions. The potential answers are clear.
Relevance of Q/A: The questions and answers in the test are related to the lesson topic.
Feedback: The system provides the user feedback as to his or her test performance and the correct answers to the given questions.

Comments:
Supplementary Lessons (Hyper-Lessons)

Knowledge:

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**Record Keeping Module**

**Information:**

**Thoroughness:** All the worker’s performance knowledge required is included.

**Accuracy:** All the knowledge about the worker’s training performance is accurate.

**Sequence and Organization:** The knowledge about the user’s performance is organized on an easy to read format.

**Comments:**

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**Comments:**

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### System Overall

### Efficiency and Applicability:

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<td>Overall Quality</td>
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**Feedback:** The instructions and messages given by the program are clear

**User Control:** The user can control what information is accessed.

**Potential Actions:** The actions the user can take are clear at all stages.

**Response Times:** The time it takes the system to respond to the user’s commands is adequate.

**Overall Quality:** The overall impression of the system
Comments:

Positive Aspects of the System:

Negative Aspects of the System (e.g., did you have any unexpected errors while using the system, unclear commands, etc.):

Do you believe that the program is worthwhile of your (your employee's) time? (Yes/No)
Would you recommend this program to your peers? (Yes/No)

Other Comments or suggestions: