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The development of Expert System for Actuated Control of Traffic (EXACT) at isolated intersections

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The Ohio State University, 1992
THE DEVELOPMENT OF
EXPERT SYSTEM FOR ACTUATED CONTROL OF TRAFFIC (EXACT)
AT ISOLATED INTERSECTIONS

DISSERTATION

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

by

Ali Saeed Al-Ghamdi

*****

The Ohio State University

1992

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Major Field: Civil Engineering
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS. ................................................................. ii  
VITA .............................................................................................. iii 
LIST OF TABLES ........................................................................... viii  
LIST OF FIGURES ........................................................................ ix  
ABSTRACT .................................................................................. xii  

CHAPTER I .......................................................................................... 1  
INTRODUCTION ................................................................................ 1  
1.1 Background and Motivation .................................................... 1  
1.2 Scope and Limitations of the Study ....................................... 8  
1.3 Objectives of the Study ......................................................... 11  
1.4 Organization of the Study ....................................................... 11  

CHAPTER II .......................................................................................... 14  
LITERATURE REVIEW ..................................................................... 14  
2.1 Introduction ............................................................................. 14  
2.2 Traffic-Actuated Control at Isolated Intersections .............. 15  
2.2.1 Traffic Control Concepts ................................................ 16  
2.2.2 Urban Street Control ...................................................... 17  
2.2.3 Isolated Intersection Control ......................................... 18  
2.2.4 State-of-the-art Hardware ............................................... 20
2.2.4.1 Traffic Signal Controller Units ................................................................. 20
2.2.4.2 Detectors ..................................................................................................... 23
2.2.5 Signal Timing ................................................................................................. 25
2.3 Expert Systems for Civil Engineering Applications ......................................... 34
  2.3.1 Historical Background of Expert Systems .................................................... 35
  2.3.2 Who are the Expert and the Potential User? .................................................. 38
  2.3.3 Expert Systems in Transportation ................................................................. 41

CHAPTER III ........................................................................................................... 41
DEVELOPMENT STAGES OF EXACT .................................................................... 48
  3.1 A Knowledge-Based Expert System Approach ............................................... 48
  3.2 The Knowledge-Base Expert Systems for Traffic Actuated Control at
    Isolated Intersections ........................................................................................... 55
  3.3 Stages of EXACT's Development ..................................................................... 56
    3.3.1 Define the Variables Pertinent to the Study ................................................ 58
    3.3.2 Implementation Tool (Shell Selection) .......................................................... 63
      3.3.2.1 PC Plus Features ...................................................................................... 67
      3.3.3 Knowledge Acquisition .............................................................................. 68
        3.3.3.1 The Selection of an expert ..................................................................... 69
        3.3.3.2 Our Expert's Criterion of Design ......................................................... 70
        3.3.3.3 Acquiring the Knowledge from the Expert .......................................... 73
          3.3.3.3.1 Discussion ......................................................................................... 73
          3.3.3.3.2 Capture ............................................................................................. 74
          3.3.3.3.3 Organization ..................................................................................... 78
      3.3.4 Knowledge Representation and Building the Knowledge Base .................. 82
      3.3.5 Building EXACT Knowledge Base ........................................................... 86
5.2 Recommendations ........................................................................................................ 191

REFERENCES ..................................................................................................................... 194

APPENDIX A: EXACT's Parameters ................................................................................. 199
APPENDIX B: EXACT's Rules ......................................................................................... 218
APPENDIX C: Diagrams of Knowledge Base ............................................................... 291
APPENDIX D: Outside Experts Testing of EXACT ....................................................... 298
APPENDIX E: Our Expert's Testing of Knowledge Base .............................................. 317
APPENDIX F: GLOSSARY .............................................................................................. 350
LIST OF TABLES

Table 2.1. Some Developed Expert Systems in the Transportation field.....47
Table 3.1. The Related Variables form Literature..............................62
Table 3.2. The Updated Variables' List.............................................81
Table 3.3. The Intersections Used in the Real Case Examples...............138
Table 3.4. The Agreement Between EXACT and Outside Experts..........146
LIST OF FIGURES

Figure 1.1. Scope of the Study ......................................................... 10
Figure 1.2. Organization of the Study .............................................. 13
Figure 2.1. A Typical Architecture for an Expert System .................... 40
Figure 3.1. The Key Players in an Expert System Development .......... 50
Figure 3.2. The Typical Architecture of an Expert System .................. 54
Figure 3.3. The Geometric Configurations covered in this Research .... 60
Figure 3.4. The Typical Features of Expert System Development Tools .. 66
Figure 3.5. The Passage Time Values Recommended by the Expert ....... 72
Figure 3.6. The Knowledge-Acquisition Process ............................. 76
Figure 3.7. A Sample of Rule Draft ................................................. 80
Figure 3.8. The Categorization of the Expert Knowledge .................... 83
Figure 3.9. A Sample Diagram for a small Piece of Knowledge Obtained form the Expert .............................. 84
Figure 3.10. The Relationships of Frames in a Hypothetical Knowledge Base ...................................................... 87
Figure 3.11. The Frame Structure of EXACT ................................. 89
Figure 3.11. The Architecture of EXACT ....................................... 89
Figure 3.12. The Properties of the Root Frame ................................. 94
Figure 3.13. Information to the User Provided by

                        TRANSLATION Property ........................................... 95
Figure 3.14. The List of Parameters of the Root Frame ...................... 97
Figure 3.15. The Rules for Instantiation in the Root Frame ................. 98
Figure 3.16. The Properties of the DESIGN Subframe ...................... 99
Figure 3.17. The Properties of the Modification Subframe ................. 100
Figure 3.18. The Properties the OPERATING Subframe .......... 101
Figure 3.19. The Properties of the Parameter GRADE .......... 104
Figure 3.20. The Properties of the Parameter CONSTRUCTION ... 106
Figure 3.21. The Properties of the Parameter VOLUME1 ........ 107
Figure 3.22. The HELP Statement at the STREET Prompt ........ 109
Figure 3.23. The Properties of the Parameter STOPLIN .......... 110
Figure 3.24. The Parameters of the Subframe Design .......... 111
Figure 3.25. The Parameters of the Subframe MODIFICATION ... 112
Figure 3.26. The Parameters of the Subframe OPERATING ...... 113
Figure 3.27. The ARL Form a Rule ........................................ 115
Figure 3.28. The Process of Developing the ARL Rules in EXACT ............................................................... 117
Figure 3.29. The English Form of A Rule ......................... 119
Figure 3.30. The Properties of the Parameter MOVE1 ............ 121
Figure 3.31. A Rule with a =G Function in its Action Part .... 122
Figure 3.32. Stages of the Testing Process of EXACT ........... 125
Figure 3.33. The Commands Menu and the Output's Destinations ................................................................. 127
Figure 3.34. Tracing the Goal Parameter DIME .................... 128
Figure 3.35. Rule 54 Passes .............................................. 129
Figure 3.36. EXACT Completed Tracing DIME ..................... 130
Figure 3.37. The First Case Characteristics ......................... 133
Figure 3.38. EXACT's Solution for the First Case ............... 134
Figure 3.39. The Second Case Characteristics ....................... 136
Figure 3.40. EXACT's Solution for the Second Case ............. 137
Figure 3.41. The Case Study Characteristics ....................... 141
Figure 3.42. EXACT's Solution for the Case Study ............... 142
Figure 4.1. EXACT's Modules of Solution ......................... 149
Figure 4.2. The Command Menu ........................................ 153
Figure 4.3. Inputs and Outputs of EXACT ............................ 157
Figure 4.4. An Example for a Consultation ............................ 158
In this research the sciences of artificial intelligence (AI) and traffic engineering are integrated through the development of EXACT (EXpert System for ACTuated Control of Traffic at Isolated Intersections). EXACT was developed to provide a practical methodology for assisting traffic engineers in the selection of the appropriate traffic-actuated control—including the type of controller and its features, the type of detector and its configuration, and time settings—at isolated intersections. The development of EXACT was based on advice from a long-experienced traffic engineer from Columbus, Ohio. The system is a rule-based, consisting of more than two-hundred rules. EXACT has a user-friendly inference mechanism through textual messages and graphics with which EXACT can constantly provide the user. The system was evaluated and tested by experts who never participated in the development stages of EXACT; and the results of testing are very positive. EXACT can be run on PC computers with minimal requirements of hardware.
1.1 Background and Motivation

Most U.S. cities are served by a well-planned, highly developed system of streets. Growth in traffic demand, however, seems to exceed the ability to provide new or expanded streets. This pressure results in great emphasis on operational and management improvements in order to use existing facilities, including streets, highways, and freeways as efficient as possible [ITE, 1985]. Today, approximately two-thirds of all vehicle-miles of travel, and an even higher percentage of vehicle-hours of travel are on facilities controlled by traffic signals (i.e., signalized intersections) [ITE, 1985]. Therefore, the efficiency of traffic-signal operation is a major determinant of urban vehicular traffic flow.

Signalized intersection control concepts fall into the following categories: (1) Isolated intersection control, (2) Arterial intersection control, (3) Closed network control, and (4) Areawide system control. These concepts are described in the next chapter. This dissertation deals with isolated intersection control. Two types of control categorize the traffic signal concepts at isolated intersections. In the first type, pretimed signal control, the right-of-way at an intersection conforms to a predetermined schedule regardless of the existing traffic demand. The other type, the focus of this research, is the traffic-actuated signal control (traffic-actuated control), in which the green time is adjusted continuously in accordance with real-time measures of traffic demand registered by vehicle detectors (sensors) placed on one or more of the approaches. This type of control is divided into three modes of operation: full-actuated control, semi-actuated control, and volume-
density control. With full-actuated control and volume-density, control detectors are required in all approaches whereas in semi-actuated control detectors should be placed in the minor street only.

According to NEMA (the National Electrical Manufacturers Association, 1975) a detector is a device for indicating the presence or passage of vehicles or pedestrians. Several types of detectors can be used with traffic-actuated control. The most common types are inductive loop detectors, magnetometric detectors, and magnetic detectors [ITE, 1987]. The inductive loop detector senses a decrease in the inductance of its sensor loop(s) during the passage of a vehicle in the zone of detection. The magnetometer detector measures the difference in the level of the earth's magnetic forces caused by the passage or presence of a vehicle near its sensor. The magnetic detector senses changes in the earth's magnetic field caused by the movement of a vehicle near its sensor. (NEMA provides the specifications and features of these types of detectors.) A microwave detector is another choice of detector, but due to its sophisticated operation and difficult maintenance, it is not widely used.

Besides the yellow change and red clearance intervals, the basic timing settings in a traffic-actuated control are minimum green time, passage time, and maximum green time (Max I and Max II). The appropriate selection of these time settings exerts a profound influence on traffic flow at isolated intersections [ITE, 1985]. Typically, operational efficiency and safety are taken into consideration in the selection of these settings. Minimum green time, the first timed portion of the green indication, is set to accommodate the storage of vehicles waiting between the detection zone and the intersection. The passage time (also called vehicle interval,
vehicle extension, unit extension, or preset gap) is the time required by a vehicle to travel from the detector point to the stopline during the green time. This time also represents the maximum gap between vehicle actuations. That is, once this time gap is longer than a preset passage time, a vehicle will lose the green, and the yellow interval will start. The maximum green time determines the maximum length of time that a green indication can be held. This concept is important during peak hours, when longer green intervals are necessary. Although green settings have been quantified mathematically for ideal situations, real-life cases are most likely far from ideal. The traffic engineer should bear this in mind in selecting green settings. For example, the demography of an area affects passage time. Elderly people in a residential area drive more slowly than people in a business area, where drivers are travelling faster and more aggressively.

The typical actuated-controller unit provides the traffic engineer with several features, including a type of detection MEMORY (i.e., LOCKING or NON-LOCKING), RECALL (ON or OFF), and EXTENSION. In the LOCKING detection mode of operation, the detection of a vehicle is held by the controller unit for future utilization, even after the calling vehicle leaves the detection area. The detection of a vehicle will be retained until the call has been satisfied by the display of the appropriate green indication. In the NON-LOCKING detection mode, the detection of a vehicle is forgotten by the controller unit as soon as the vehicle leaves the zone of detection. In RECALL, another operational mode for an actuated controller, a phase is displayed each cycle whether a demand exists or not. For example, if the traffic engineer wants to have the green indication always set for the major street unless there is a demand on the minor street, he/she can set the RECALL on the ON mode. EXTENSION is a feature associated with the placed
detector. When this feature is selected, a call is delayed for a specific time set in the controller unit by the traffic engineer.

The area of traffic-actuated control at isolated intersections has received wide attention from traffic researchers. Most past studies have emphasized signal timing using optimization, simulation and statistical analysis. However, there is a lack of specific guidelines concerning the selection of the type of traffic-actuated control and its features, the type of the detector, and the time settings for a particular intersection. This lack can be attributed to the complexity of the selection process, including the wide variety of geometries and traffic characteristics, as well as to drastic changes in the actuated-control equipment itself [Tarnoff and Parsonson].

A wide range of geometric configurations for signalized intersections exists in the real world, such as the four-legged intersection, the five-legged intersection, and the T-intersection with different angles between legs (approaches). An approach can have a combination of a wide variety of traffic movements, including through movement, left-turning movement, right-turning movement, and lane-shared movement. All these and other geometric features (i.e., stopline location, grade, and lane width) contribute the complexity of the selection process.

Traffic characteristics include volume, speed, and drivers' behavior. Traffic volume (demand) fluctuates at isolated intersections during the day. During peak-hour periods (morning or evening peak) demand on an approach may reach the approach's capacity. Each approach at an intersection has its speed limit. Approaches with speeds of 35 miles per hour (mph) or less are low speed
approaches, and approaches with speeds higher than 35 mph are high-speed approaches. Drivers' behavior may differ from one intersection to another based on the demographic characteristics of the location of that intersection. That is, drivers in a business area tend to drive faster than those in a residential area. Drivers' behavior along with the diversity of traffic characteristics make the selection process more complex.

Moreover, the revolution in technology over the past two decades from mechanical equipment to solid state (employing microprocessor technology) and digital electronic-based equipment has contributed to the complexity of traffic-actuated control and has caused differences in designing practices all over the United States [ITE and TRB 166]. A recent report which conducted a survey of state-of-the-art of traffic signal control equipment [TRB, 1990] states: "However, the revolution in electronics has brought us to microprocessor-based signal control equipment that is far more powerful and flexible than anything dreamed of just a decade or two ago .... Practicing traffic engineers, schooled in the signal equipment of the 1950s, 1960s, and 1970s, may not be familiar with the powerful new tools available to help solve traffic congestion problems." In this study of the TRB a survey of practices was undertaken. The responses to this survey show that most of the state departments of transportation and local or county transportation agencies use different actuated controller equipment (i.e., NEMA and Type 170/179 equipment). Since different types of equipment offer different features, engineering practices differ considerably.

Rapid technological advances in state-of-the-art equipment along with the variety of geometric configurations of intersections and the wide variation in traffic
characteristics have made it difficult to find specific guidelines for selecting the appropriate type of actuated controller with its features, the type and the location of detector, and the time settings for a particular intersection [Tarnoff and Parsons]. Most local transportation agencies have developed their own guidelines for the selection process based on their engineer's experience [ITE, 1982]. Traffic engineers' judgment should be exercised in this selection [ITE(1982), Zozaya and Hendrickson, and ITE (1985)].

Because of the complexity and the need for the traffic engineers' expertise explained above, this research presents a new approach to assist traffic practitioners in the selection process: a knowledge-based expert system. Recently, expert systems technology has received wide attention in the field of transportation, for an expert system lends itself to many problems in this field. An expert system is a computer program containing human expertise, judgments, and rules of thumb to provide one or more solutions for a specific problem. Expert systems can be applied to an ill-structured problem where an algorithmic solution is not applicable. Although numerous analytical studies have been conducted that develop statistical relationships for various types of control at isolated intersections, they have been always conducted under assumptions too restrictive to permit their application. Excessive reliance on simulation can lead to unrealistic conclusions [Tarnoff and Parsons]. Numerous computer models have been developed (using linear programming and simulation) to aid traffic engineers in selecting appropriate phase distributions and control strategies [FHWA, 1982]. Despite the existence of such analysis models, a number of problems exist that prohibit the models' useful application and require "expert" attention [Zozaya and Hendrickson, 1987]. Zozaya and Hendrickson emphasize that, as Ozanne states, a common shortcoming of
existing computer models is the inability to deal with uncommon geometries (e.g.,
five-legged intersections in which intersections are not close together) or special
design considerations. For instance, SOAP84 (Signal Operation Analysis Package
based on optimization) and TEXAS (based on simulation) are two widely common
models for traffic signal design. Bullen et. al. (1988) state that: "The software
that is currently used has only limited applicability. SOAP84 model depends
heavily on the approach of Webster which is mainly for pretimed signals. Although
SOAP84 does provide some assistance for dealing with vehicle actuation, it does
not attempt to provide a complete analysis capability for the many options that are
available. The TEXAS model is not widely circulated. It is a microsimulation of an
intersection with vehicle-actuated signals, but provides no direct optimization
capability. The model is rather slow, and it is not clear how well it deals with all of
the individual timing parameters for fully actuated volume density control." As a
result of such limitations, we believe that a knowledge-based expert system will
help us improve the analysis of the design and operation for traffic-actuated control
at isolated intersections. This technique permits the incorporation of experts'
heuristics and empirical knowledge in dealing with the complex factors that these
computer models could not handle in the past, such as pavement problems,
abnormal geometric features, the presence of construction problems (i.e., a lane
closure or street closure), sudden equipment failure, and drivers' behavior. That
is, with the expert system we attack the problem of the selection process directly
through modeling the expertise of human experts who have been working with real-world problems on a daily basis. Additionally, unlike the existing computer models,
the expert system developed in this research has the ability to explain its reasoning
process in detail so that the user will be very well informed about why a piece of
information is required during the consultation course and how a specific solution has been reached.

1.2 Scope and Limitations of the Study

The main focus of this research is actuated control at an isolated intersection, particularly in the following:

1. Selection of an appropriate type of detector, its location, and its configuration (how many detectors and in what dimensions).

2. Selection of the type of controller unit and the features associated with it, such as 
   
   RECALL, MEMORY, and EXTENSION.

3. Selection of the appropriate time settings, including initial green time, passage time, and maximum green time into the controller unit.

In this research, we take advantage of a traffic engineer's experience in Columbus, Ohio, to build practical guidelines for the selection process. Taking a heuristic approach, we model our human expert's expertise (i.e., judgment, rules of thumb, educated guesses) through an expert system. The resulting expert system, EXACT (EXpert System of Actuated Control for Traffic at Isolated Intersections), can provide a complete actuated-control design at an isolated intersection with specific geometry and traffic characteristics. It can be thought of as a consultation tool especially for traffic engineers who have some basic background in traffic-actuated control.

The design of EXACT, based on our expert in Columbus, Ohio, covers the most typical geometric intersections. Therefore, EXACT cannot solve all isolated
intersection problems everywhere. However, it can suggest a solution for any intersection with the one of the geometric configurations provided in EXACT. In other words, EXACT does have some limitations in terms of application. One is that EXACT designs isolated intersections but not coordinated intersections. Coordinated intersections, beyond the scope of this research, are typically operated through connected controller units. Yet, with some modifications in EXACT's frame structure, it would be possible to extend EXACT to cover coordinated intersections. The difficulty in this extension would be to find an expert in the area of signal coordination who can afford the time to converse with the would-be modifier of EXACT.

The ability to design only those isolated intersections with typical geometric configurations is another limitation of EXACT. Because of the limited geometric types in Columbus, EXACT can design approach configurations of five lanes and fewer. As presented in Chapter Three, EXACT can handle twenty-eight lane combinations. Figure 1.1 presents the scope of this study.
Figure 1.1. Scope of the Study
1.3 Objectives of the Study

The main objective of this research is to develop a practical methodology through the use of a knowledge-based expert system for assisting traffic engineers in the following:

1. Selecting an appropriate type of actuated signal controller and its features, typically including MEMORY, RECALL, and EXTENSION.

2. Selecting the appropriate time settings (i.e., the initial green time, the passage time, and the maximum green time—MAX I and MAX II) for the actuated controller. These time settings should enhance the operational performance at isolated intersections.

3. Selecting the detector system, including the type of detector, its placement, and its configuration (i.e., the dimensions for a loop detector and the number of detectors for a magnetometer or a magnetic detector).

1.4 Organization of the Study

The organization of this study is summarized in Figure 1.2. After a general introduction and description of the study's scope and objectives in Chapter One, a detailed review of the past practice and the research literature of traffic actuated control at isolated intersections is presented in Chapter Two. Although many studies have been conducted in the area of traffic control, this chapter covers the most recent and pertinent ones. Research methodology is presented in Chapter Three. Since expert systems technology is the tool used in this research, this chapter introduces the basic elements of expert systems and its applicability to the problem.
Moreover, the stages in the development of EXACT are explained in depth, including shell selection, knowledge acquisition, knowledge representation, and testing. Chapter Four emphasizes the installation and the hardware requirements for EXACT and shows how to run a consultation. Conclusions of the research and recommendations for future research are presented in Chapter Five. Several appendices follow the final chapter.
Figure 1.2. Organization of the Study.
CHAPTER II
LITERATURE REVIEW

2.1 Introduction

In this chapter a comprehensive literature review on traffic signal control at isolated intersections has been conducted. Many studies on the subject have been carried out in the past. Most of these studies have used statistical analysis to evaluate the operational performance of different forms of actuated control at isolated intersections. Results from several studies, sponsored by the Federal Highway Administration (FHWA), have been generalized to act as general guidelines in the design of traffic signal control at isolated intersections. Yet, because of the complexity of the problem and the rapid changes in the state-of-the-art of actuated equipments, the literature reveals that most state transportation agencies have developed their own guidelines. Current practice has emphasized the role of traffic engineers' judgment in the designing process. As a result, the literature presents not strict rules, but some rules of thumb used by traffic practitioners.

This chapter falls into two parts. The first deals with traffic-actuated control at isolated intersections. Several significant studies are presented. The other part concerns expert system technology and its acceptance and potential applications in the domain of transportation engineering.
2.2 Traffic-Actuated Control at Isolated Intersections

The original of traffic control signals can be traced back to the manually operated semaphores first used in London as early as 1868. The first electric signal in the United States was developed by James Hoge and installed in Cleveland, Ohio in 1984. This was followed by the introduction of interconnected signal in 1917 in Salt Lake City, Utah [J.H. Kell and Fullerton]. By this time, automobile ownership and usage was expanding rapidly and effective vehicle traffic control was recognized as a growing problem. The evolving need led to the development and implementation of actuated signals in 1928.

Since then, traffic signal technology has greatly expanded and has become a critical element in the safe and efficient control of traffic on our streets and highway. Today's traffic signals are defined as: "power-operated traffic devices which alternately direct traffic to stop and to proceed. More specifically, traffic signals are used to control the assignment of right-of-way at locations where conflicts exist or where passive devices, such as signs and markings, do not provide the necessary flexibility of control to properly move traffic in a safe and efficient manner [FHWA, 1983]."

Traffic signals have a significant impact on traffic flow and can operate to the advantage or disadvantage of road users. Consequently, the appropriate application, design, and operation of traffic signals is critical to the orderly movement of traffic at specified locations and may be expected to increase traffic handling capability of the intersection. Conversely, unjustified, poorly designed, improperly operated, or inadequately maintained traffic signals can cause excessive, unnecessary delay and reduced intersection capacity. Additionally, inefficient
operation disturbs drivers and is silently stealing dollars from their pocket in increased fuel costs, longer trip times. Research have demonstrated the effectiveness of signal system improvements in reducing vehicular delays, stops, fuel consumption, emission of pollutants and so forth, as explained in Traffic Control Systems Handbook [1985].

2.2.1 Traffic Control Concepts

The area of traffic control is wealthy of concepts which give a basic understanding for applying strategies of operation. These concepts can fall into two areas: freeways and urban streets.

Control concepts for freeways are associated with ramp control, mainline control, and corridor control and surveillance. Entrance ramp control is the most widely used form of freeway traffic control [ITE, 1985]. The main objective of this control is to reduce the operational problems resulting from freeway congestion. The principle of entrance ramp is the limiting of the number of vehicles entering the freeway so that the capacity of the freeway will not be overused. Thus, some traffic desiring to enter the freeway will be required to wait at the entrance ramps before being allowed to enter the freeway. This can be conducted by the entrance ramp control which maintain uninterrupted noncongested flow on the freeway for as long as possible by transferring the delay factor from the freeway location to the entrance ramp location.

Another concept of freeway control is the use of controls for traffic on the freeway mainline itself. This control is concerned with the regulation, warning, and guidance of traffic on the freeway lanes in order to improve the uniformity and
stability of traffic flow, to reduce the potential for rear-end collisions if congestion
does develop, to facilitate incident management and recovery from congestion, and
to divert freeway traffic to alternate routes in order to make better use of corridor
capacity. Mainline control is typically implemented through one or more of the
following: driver information systems, variable-speed control, lane closure, and
reversible lane control.

The purpose of corridor control is to achieve full utilization of all available
facilities in the freeway corridor. A freeway corridor includes the freeway and its
ramps, frontage roads, parallel arterial streets, and cross streets that are links
between freeway ramps and alternative routes. The key element of corridor control
is surveillance, which is action-oriented monitoring of traffic conditions on the
corridor links.

2.2.2 Urban Street Control

Urban street control can be divided into four categories [ITE, 1985]:

1. Isolated intersection control.
2. Arterial intersection control (open network).
3. Closed network control.
4. Areawide system control.

Isolated intersection control is a form of signal control for a signalized intersection
through which the flow of traffic is controlled without giving any consideration to
the traffic at adjacent signalized intersections.

Arterial intersection control (open network) is a form of signal control for
signalized intersections along an arterial street in which major consideration is given
to the provision of progressive traffic flow along the arterial. Opposing to the isolated intersection, in the arterial intersection control attention must be given to operating the signals as a system through coordination. According to the Manual on Uniform Traffic Control Devices, traffic control signals within 1/2 mile of one another along a major rout should be operated in coordination, preferably with interconnected controllers.

In closed network control coordination for a group of adjacent signalized intersections should be considered. The control of signals in the central business district (CBD) is a typical example for such a control.

Areawide system control treats all of the traffic signals in a city or a metropolitan area as a total system. The individual signals within this area may be controlled by isolated, open-network, or closed-network concepts. Closed circuit television camera and monitors are employed to enable operators to view traffic at various locations under this type of control.

2.2.3 Isolated Intersection Control

Since the concern of this research is traffic control at isolated intersections, a detail will be given in this section on traffic signal control concepts at these locations. Two basic categories characterize traffic signal control concepts for isolated intersections:

1. Pretimed signal control.
2. Traffic-Actuated signal control.

According to Traffic Control Systems Handbook, pretimed control assigns the right-of-way at an intersection according to a predetermined schedule. The
sequence of right-of-way assignments, and the time interval for each signal indication in the cycle is fixed, based on historic traffic patterns. The major elements of pretimed control are (1) fixed cycle length, (2) fixed phase lengths, and (3) number and sequence of phases. Moreover, this type of control is appropriate for intersections with predictable traffic patterns, or frequent occurrence of saturated conditions.

In contrast to pretimed control, traffic-actuated control of isolated intersections attempts to adjust green times continuously in accordance with real-time measures of traffic demand obtained from vehicle detectors placed on one or more of the approaches to the intersection. Three types of actuated control have been widely used: (1) Full-actuated control, (2) Semi-actuated control, and (3) Volume-density control. Full-actuated control requires detectors for all phases with each phase timed according to preset timing parameters. Full-actuated control allows skip phasing when there is no demand on the street. This type of control is primarily used at the intersection where demand fluctuations occur. Instead, detectors are required only on the minor street approach(s) in semi-actuated control and is especially effective at intersections where the major street has a relatively uniform flow and the major street has low volume with random peaks. Volume-density control is a refined version of actuated control and is mostly recommended at isolated intersections of major high-speed roadways with considerable unpredictable fluctuations. In contrast to other types of actuated control, this type needs traffic information early enough to react in time to accommodate existing demand. In other words, detectors on all approaches should be placed far in advance of the intersection.
2.2.4 State-of-the-art Hardware

Over the past decades, the state of the art technology of traffic signal control equipment has advances dramatically. The drastic change from electromechanical to microprocessor technology has greatly enhanced the capabilities of such equipment concerning the flexibility in signal phasing and controller features. New designs and installation techniques have improved the operational efficiency of vehicular detectors. Signal displays have been improved to require less maintenance and reduced energy consumptions yet provide a clear, attention-getting signal. In this section, a comprehensive description, based on the literature, regarding controller equipment, detectors, and signal displays will be summarized.

2.2.4.1 Traffic Signal Controller Units

The main objective of the controller unit is to provide the timing and display selection functions for the controller assembly. Traffic-actuated controllers select the right-of-way, change and clearance intervals assigned to any independent movement of traffic and extend green durations based on real-time demand registered by vehicular detectors placed in the roadway. Phases without demand can be omitted from the signal sequence; phases with minimal demand are provided only enough green time to satisfy that demand, whereas phases with heavy traffic flows are extended to accommodate the additional vehicles waiting in that phase [TRB, 1990]. In isolated signal control, the controller acts as a stand-alone unit and times the assignments for right-of-way independently, unaffected by other devices [ITE, 1985].

The evolution of traffic signal controller hardware parallels that in related industries. The drastic technological advancement in electronics has contributed
substantially in this evolution. Signal controller unit hardware has evolved from the motor-driven dials and camshaft switching units to the adoption of general-use microprocessors for a wide variety of intersection-control and special-control concepts. The only commercially available controller units in the early years of traffic signal control were the electromechanical type. Later, several manufactures introduced semiautomated and fully-automated controllers which were equipped with vacuum tube-type electrical circuitry for timing functions. The traffic engineer was introduced to interval and phase timing, adjustable via knobs on a control panel. The transformers and vacuum tubes in these analog-type units generated considerable heat, initiating requirements for forced-air circulation and filtering in controller cabinets.

The introduction of the transistor as a functional replacement for vacuum tube heralded the use of low-voltage circuitry with only a fraction of the former heat generation. During the mid 1960s, transistorized circuits were first used for timing and phasing functions in traffic control. Lower operating temperatures, increased component life, and digital timing assured timing accuracy and eliminated fluctuations. Also introduced during this period was the solid-state load switch for lamp circuits. A wide range of component and equipment arrangements from manufacturer to manufacturer also was prevalent during the 1960s.

The next major step in the evolution process was the development of the integrated circuit (IC). Microchip technology had shrunk components, literally, to microscopic size in some cases. These very small ships were then linked together in circuits and sealed within an IC envelop. Today hundreds, even thousands, of solid state devices can be made part of an IC which is smaller than a postage stamp.
This technology made the microprocessor a reality. Previously, a computer was a large and environmentally sensitive unit. The advent of the microprocessor led to the development of microcomputers—small, lightweight, low-cost units seen everywhere today. Microprocessors were quickly incorporated into new signal controller designs by the industry. They are, today, the heart of solid-state controller units, both the pretimed and the full-actuated types.

Traffic actuated controllers provide several features that have strong impact on the operational performance of the intersection. One feature is concerned with controller detection modes. There are two controller detection modes: LOCKING Detection Memory and NONLOCKING Detection Memory. In the first mode of operation, the detection of a vehicle is retained by the controller unit for future utilization when the detector amplifier output ceases near the end of green or during the yellow change, red clearance, or red displays for a specific approach. This type of detection memory creates difficulties in screening out false calls which may occur, such as in a right-turn-on-red situation from the minor street. In the NONLOCKING Detection mode, the detection of vehicle is based on current occupancy of the detected field. This mode is frequently used in large loop detection. Another feature provided with an actuated controller is extended call detection (EXTENSION). In this case the detector unit holds or stretches the call of a vehicle for a preset time that has been selected by traffic engineer. The RECALL feature is an operational mode for an actuated controller unit whereby a phase, either vehicle or pedestrian, is displayed each cycle whether or not demand exists. This feature can be set on either ON or OFF mode [ITE, 1985].
2.2.4.2 Detectors

Movement of vehicles is the concern of traffic control. Inasmuch as the volume of these movements is usually fluctuating from minute to minute, it is desirable to detect a movement by installing one or more detectors in the vehicle's path. When a vehicle passes over a detector zone, an actuation (output) is sent into the controller unit, which in turn either extends the green for that vehicle or brings the green to it at the earliest opportunity. The National Electrical Manufacturer's Association (NEMA) defines a detector as "a device for indicating the presence or passage of vehicles or pedestrians. A presence detector is intended to hold the actuation or call of a vehicle for as long as it remains in the detection area or zone. It can be operated in the pulse mode, to ignore the continued presence of a vehicle stopped within the detection zone."

As indicated in Traffic Detector Handbook (ITE, 1985), vehicle detectors have been in use for over than fifty years. Manually operated traffic signals began to be replaced by fixed-time controllers in the 1920's. These machines were immediately seen to be the equivalent of blind and deaf policemen who hopefully had been well instructed in the typical traffic patterns previously observed at that intersection at that time of day. The obvious limitation of fixed-time controllers created the licentive to develop some device to measure automatically the minute-to-minute traffic arrivals previously obtained visually by the traffic officer. The first vehicle detector appears to be Charles Adler's device. A small telephone microphone actuated the signal when the driver sounded his car horn. It was first installed at a Baltimore intersection in 1928 and remained in regular service for several years, despite its unpopularity with neighboring residents. Just weeks after Adler's semi-actuated signal installation, a pressure-sensitive detector was installed
in New Haven, Connecticut. Invented by Harry A. Haugh, a professor at Yale University, the device was the first popular detector. The second important detector to appear was the magnetic type. The iron content of motor vehicles causes distortion of the Earth's magnetic field as the vehicle moves near the sensor. Magnetic flux changes in sensing coils in or near the roadway provide a method of measuring vehicle movement past them. Magnetic detectors have been in use since the early 1930's and remain popular today. Radar detectors were developed during World War II and firstly used in the 1950's and 1960's for detecting traffic. Microwave energy is beamed on an area of roadway from an antenna mounted overhead or in sidefire position on a pole. The antenna is angled slightly toward traffic, creating a Doppler effect on the reflected signal. Radar detectors are expensive and can be serviced only by technicians with an FCC operating license. Inductive Loop Detectors (ILD), the most widely used type today, began to be used in the early 1960's. Like the radar detector, it uses principles of electromagnetic. The loop consists of one or more turns of insulated wire wound in a shallow, rectangular slot sawed in the roadway. At curbside the two ends of the wire are carefully spliced to a factory-twisted and shielded lead-in cable that is led to an intersection cabinet housing the electronics unit. This unit drives energy through the loop at radio frequencies typically in the range of 20 to 200 KHZ. A vehicle entering the loop will absorb some of the radio frequency energy beaus of eddy currents created in the metal periphery. The inductance is reduced, causing the resonant frequency to increase. At this point, various designs of ILD electronics process phase, frequency, amplitude or impedance changes to actuate the detector's output relay. The ILD electronics unit is quite inexpensive, selling in 1981 for approximately $65 to $120 per channel of detection. Installation requires traffic to be disrupted and pavement to be cut. ILD detection is very flexible and can be
highly dependable. The zone of detection can be varied widely, either passage or presence modes are selectable, and calls cab either delayed or extended. The ILD is currently the most popular detector for individual intersections, signal systems, and freeway surveillance. Magnetometer detector is quite different from the magnetic detector. This type was introduced in the mid 1960's. A ferrous vehicle is more permeable than is air to the lines of the earth's magnetic field. Therefore, flux lines in the vicinity of a vehicle will bend in order to pass through it. The concentration of flux is known as the vehicle's "magnetic shadow," and it is present whether the vehicle is in motion or at rest. Magnetometer probes buried in the roadway sense the vertical component of the magnetic shadow. A voltage activates either vehicle presence or passage circuitry, closing the output relay. This type of detectors are used primarily to provide vehicle counting and passage detection at individual intersections. Large-area presence detection requires a series of probes. The VIDS (Video Imaging Detector System) detector is thought to be the future detectors. This type uses digitized video-imaging techniques to track the trajectories of all traffic on an approach. A prototype system has been tested recently.

2.2.5 Signal Timing

Signal timing is one subject of signal controls which have received substantial attention from researchers because of its critical role in operational performance at signalized intersections. Having selected control equipments, the traffic engineer should design a timing plan to fit traffic demands on each approach. This timing plan (strategy) is function of the type and capability of the controller and the operational (traffic) requirements of the intersection. In actual practice, the timing parameters for new or improved signalized intersections are greatly based on timing settings (initial green time, passage time, and maximum green time defined in Chapter one) that have proved effective for similar types of intersection, traffic
conditions, and equipment. These timing settings are implemented and traffic flow is observed after the signal is turned on. If, after the traffic has stabilized, excessive stops or delays occur, the timing is adjusted accordingly. The functional objective of signal timing is to alternate the right of way among the various phases to accomplish the following [J.H. Kell and Fullerton, 1982]:

* Provide for the orderly movement of traffic.
* Minimize average delay to vehicles and pedestrians.
* Reduce the potential for accident-producing conflicts.
* Maximize the capacity of each intersection.

Several techniques have been used in computing signal timing intervals (green time, yellow, clearance, and cycle length). Optimization, simulation, and empirical analysis based on statistics are the most popular techniques in signal timing. Webster, for instance, utilized computer simulation and extensive observations to provide an excellent study of isolated intersections [ITE, 1985]. Webster developed the classical equation:

\[
d = \frac{C(1-y)^2}{2(1-yX)} + \frac{x^2}{2q(1-X)} - 0.65 \left[\frac{C}{q^2}\right]^{1/3} X^{(2+5y)}
\]

Where:
\[d = \text{Average delay per vehicle on the intersection approach}\]
\[C = \text{Cycle length}\]
\[y = \text{Proportion of the cycle which is effective green for the phase under consideration}\]
\[q = \text{Flow rate}\]
$X =$ The degree of saturation. This is the ratio of the actual flow to the maximum flow which can be passed through the intersection from this intersection approach and is give by $X = \frac{q}{S}$

$S =$ Saturation rate (1,800 vph)

Webster shows that a critical lane can be designated and defined as the one with the highest ratio of flow to saturation. This ratio is denoted by the symbol $Y$, where $Y = \text{Max} \left( \frac{q}{X} \right)$ for a given phase. An optimum cycle-length ($Co$) formula developed by Webster for actuated applications:

$$\text{Co} = \frac{1.3 \ L}{1 - \sum_{i=1}^{n} Y_i}$$

Where;

$Co =$ Optimum Cycle length, sec.

$L =$ Lost time for all phases $= n \times 1 \times R$

$n =$ Number of phases

$l =$ Average lost time per phase, sec/sec.

$R =$ Time during each cycle when all signals display red simultaneously, sec.

$Y_i =$ Critical lane flow (ith phase, vph) saturation flow (vph).

Webster further recommended that the distribution of the green time to each phase be proportional to the critical lane volumes on each phase. For example, for two phase operation he suggested the following formula:

$$G_t \ (\text{net green time}) = Co - A_1 - A_2 - nl$$
Where:

\[ C_0 = \text{Optimum cycle length, sec} \]
\[ A_1 = \text{Yellow time on phase 1, sec.} \]
\[ A_2 = \text{Yellow time on phase 2, sec.} \]
\[ n = \text{Number of phases} \]
\[ l = \text{Lost time per phase, sec.} \]

One widely used approach of signal timing modeling is the empirical technique. In this case, the basic relationships within the model were arrived at experimentally through extensive field studies. The Highway Capacity Manual is an example of an empirical model [FHWA, 1982]. This modeling technique implement statistics for analytical purposes. Poison distribution is a popular example used frequently to describe arrivals during a given period in a traffic stream. Stochastic modeling is another technique which relies on poison process and queuing theory. Critical Lane Movement (CLM), sometimes called critical movement analysis, is a procedure which allows for capacity and level of service determination for signalized intersections. This analysis incorporates the effects of geometry and traffic signal operation and results in level of service determination from the intersection as a whole operating unit. CLM can be used in two general categories of problems: Planning applications and Operations and Design applications. The key assumptions in this technique is that there is a combination of lane volumes which must be accommodated in one hour through the middle of a signalized intersection. The sum of these volumes (critical volume) cannot exceed the saturation flow characteristics of the intersection. Basically, 1800 vph would be the maximum value under ideal conditions for the critical volume, with 1500 vph being an average value for typical conditions [TRB, 1980].
Another modeling technique is optimization. The objective of this technique is to determine the values of specific design parameters which will optimize the operation (cycle, splits, and etc.). Usually, delay is the measure of effectiveness in optimization. That is, determining the values of such parameters to minimize delay.

The Signal Operations Analysis Package (SOAP), an example of optimization application in traffic signal design, was developed by the University of Florida Transportation Research Center. This program was written in Fortran IV on an IBM computer system. The Webster 's method was the basic criterion in SOAP development. Analysis is accomplished in SOAP by computing the various measures of effectiveness, MOE, which are: delay, stops, excess fuel consumption, degree of saturation, and left-turn conflicts. Although SOAP was designed based on pretimed operation, certain factors used to make applicable in the actuated operation. Handbook of Computer Models for Traffic Operations Analysis [1982] states that "the analysis and optimization is clearly based on mathematical approximations of the real world and therefore necessarily cannot take into account any extraordinary or erratic human behavior."

Simulation technique has been used to evaluate operational performance at a particular intersection. A simulation model is a mathematical representation of the sequence of events which comprise a process. This modeling technique is based on random distributions of such events. The reliability of this type of modeling depends greatly upon the accuracy of such distributions. Two types of modeling is involved herein: (1) microscopic modeling and (2) macroscopic modeling. In microscopic modeling each vehicle is treated as a separate unit. In macroscopic modeling a group of vehicles (platoon) is modeled. One example of simulation
models in the traffic field is the Texas Model. This is a microscopic mode developed to evaluate intersection operational performance under different types of control as well as various timing plans. While the TEXAS Model is extremely useful and powerful, several limitations warrant notice. First is the absence of any effect by pedestrians. Second is that approaches must be straight and at zero grade.

Tarnoff and Parsonson [1979] describe the results of an analysis of the benefits and costs associated with alternative forms of signal control for individual intersections. They also present the results of an extensive survey of controller acquisition, installation, and maintenance costs. This nationwide survey made use of data acquired from state, county, and municipal traffic engineering organizations. The results of this study were used to produce a set of guidelines that can be applied by the practicing traffic engineer to the selection of traffic-actuated form and in very restricted cases. The authors emphasize that although traffic engineers recognize that each type of control has its appropriate use, selection of control type is generally determined without a comprehensive analysis because of lack of guidance and supporting reference data.

Traffic Control Systems Handbook [1985] was published by the Federal Highway Administration. It presents the basic technology used in planning, designing, and implementing traffic surveillance and control systems for urban streets and freeways. Very useful information has been introduced in this handbook regarding control concepts, detectors, local controllers, selection of a system, design, and implementation. The information given in this handbook are based on Manual on Uniform Traffic Control Devices, the Manual of Traffic Signal Design, and the Transportation and Traffic Engineering Handbook.
In the Traffic Detector Handbook, the Institute of Transportation Engineers (ITE) presents complete information regarding detectors at signalized intersections, in Traffic Detector Handbook [1987]. This handbook covers detector theory and hardware, the installation and implementation of detectors, and detector specification. The handbook gives general headlines and leaves the details to traffic engineers.

The primary objective of the paper, "Adaptive Signal Control at Isolated Intersections" [Lin and et. al., 1988], is to explain the issues and research needs concerning the development of adaptive control logics for application at isolated intersections. The discussions are focused on the information needs for adaptive control, the selection between a binary choice process and a sequencing process for timing adjustment. The paper presents in detail the binary choice and sequencing process approaches and their effectiveness in improving signal operations.

Bullen [1989] has investigated the effects of actuated signal settings and detector placement on vehicle delay. He uses the EVIPAS simulation and optimization model to analyze vehicle-actuated traffic signals. Detector type and placement, traffic volume, the percentage of trucks, and minimum green and vehicle extension settings are the variables used in this study. The average vehicle delay was the criterion for evaluation. Bullen found that the optimum design for traffic-actuated signals is specific for some variables but is independent of others. The design is critical at high traffic volume. The vehicle delay is unaffected by the design parameters at low volumes. Vehicle extension was found to be the most critical variable, particularly for passage detectors where it should be at least 4.0
seconds regardless of detector placement and approach speed. The study recommends a very short vehicle interval for a presence detector of sufficient length.

The Manual of Traffic Signal Design [JHK and Fullerton, 1982] has been widely used in the area of traffic signal control. Respective chapters cover traffic signal controllers, detectors, and signal timing. It emphasizes that:

"There is no 'best' method of determining the optimum type of control for a given local intersection... In general practice, the rule of thumb is: For predictable traffic, use pretimed; for unpredictable traffic, use actuated control... Detector location and configuration is dependent on geometry of the intersection and approaches, traffic flow characteristics, and etc... One of the major difficulties in explaining detector application and design theories is the abundance (and redundancy) of terminology used in current literature. For example, a short loop detector that simply detects the passage of a vehicle at a given point is variously termed a motion detector, passage detector, unit detector, or point detector... Some jurisdictions use a single loop to cover two or more lanes. Other agencies feel that this type of loop loses sensitivity and does not provide adequate information to the controller... The choice of vehicle extension represents a trade-off between operational efficiency, cost of loop installation and maintenance, and the cost of motorist delay... To operate effectively, detectors must be properly designed and carefully installed. An improperly installed detector can seriously degrade the efficient operation of the controller or even render the controller inoperative."

The manual stresses the role of the engineer's expertise in the design of signal control. "Most local signal engineers have a 'feel' for the timing values that will be required for efficient operation... Maximizing approach capacity requires the minimum number of phases to service the demand. Accordingly, it is necessary to exercise engineering judgment to achieve the best possible compromise among these objectives... It is therefore difficult to set forth comprehensive guidelines to fit all possible situations... An actuated controller is especially effective
at intersections with wide and irregular traffic fluctuations and at isolated intersections. The manual suggests initial green times for several ranges of the distance between stopline and the detector. For example, an initial green time of fourteen seconds is recommended for the distance between 81 to 100 feet. In terms of vehicle interval (also referred to as the extension interval, unit extension, or passage time), the manual emphasizes that for maximum efficiency, the vehicle interval should be set as 'short' as possible. The authors indicate that most state transportation agencies have their own guidelines concerning the design of signal control.

From this literature review, it can be concluded that a traffic signal control's design and operation depend greatly upon traffic engineer's judgment. J.H. Kell and I.J. Fullerton state that "Most local signal engineers have a 'feel' for the timing values that will be required for efficient operation....There is no universal 'best' method of determining the optimum type of control for a given local intersection. Each type of control has its unique advantages and disadvantages....Engineering judgment must be exercised to assure that the signal would not increase the hazard or cause unnecessary delay. The Traffic Control Devices Handbook [FHWA, 1983] indicates that "While left-turn phasing and multiphased operation have advantages in some situations, they also have some drawbacks. Sound engineering judgment needs to be applied in considering their role." The Manual on Traffic Control Devices [FHWA, 1978] also emphasizes the role of the traffic engineer's judgment: "A careful analysis of traffic operations and other factors at a large number of signalized and unsignalized intersections, coupled with the judgment of experienced engineers, have provided a series of warrants that define the maximum conditions under which signal installations may be justified." Although various techniques were used in the past in the design of traffic actuated control signals, as mentioned
previously, these techniques were based on ideal conditions (i.e., good pavement condition and standard geometric configurations). That is, in real-life conditions traffic engineers face pavement problems, driveway presence, abnormal geometry, and different drivers behavior from one location to another. Unfortunately, the available models based on optimization and simulation techniques do not take all these factors into consideration, as a result, their solutions are most of the time far from practical. Tarnoff and Parsonson stress that "Numerous analytical studies have been performed that develop statistical relationships for various types of control. These studies often provide insight into the operation of signal control alternatives. However, they have always been conducted under assumptions too restrictive to permit their application to specific guidelines....excessive reliance on simulation can lead to unrealistic conclusions." These discussions motivate us to use the expert system technique as an alternative for previous techniques in order to attack the problem with our expertise. The expert system approach will help us in modeling traffic engineers' judgment and rules of thumb in the area of traffic-actuated control to derive more practical solutions. Because of the significant role of traffic engineers' experience as mentioned in the literature, we believe that the expert system technique will provide a more reliable and realistic approach to the problem than other techniques. Therefore, the expert system's literature review is presented below.

2.3 Expert Systems for Civil Engineering Applications

Before we review past expert systems research in civil engineering, a brief historical background of expert systems technology will be presented.
2.3.1 Historical Background of Expert Systems

Since World War II, computer scientists have tried to develop techniques that would allow computers to act more like humans. The entire research effort, including decision making systems, robotic devices, and various approaches to computer speech, is usually called Artificial Intelligence (AI). A collection of AI techniques that enables computers to assist people in analyzing problems and making decisions is called expert systems technology. As World War II ended, separate groups of British and American scientists were working to develop what we would now call a computer. Each group wanted to create an electronic machine that could be guided by a stored program of directions and made to carry out complex numerical computations. The principal British scientist, Alan Turing, argued that such a general-purpose machine, once developed, would have many different uses. Based on his knowledge of formal logic, Turing argued that the fundamental instructions given to such a machine ought to be based on logical operators, such as "and," "or," and "not." One could then use such very general operators to assemble the more specialized numerical operators needed for arithmetical calculations. Moreover, programs based on logical operators would be capable of manipulating any type of symbolic material that one might want to work with, including statements in ordinary language.

The American scientists, for their part, suspected that the machines were going to be expensive to build. Additionally, they assumed that they would not build very many of them. And since they were confident that they were building a machine that would perform only arithmetical calculations, they decided against using logical operators and chose instead to use numerical operators, such as "+", "-", and ">." This decision, which the British subsequently followed as well,
resulted in large computers that are essentially very vast calculating machines. In spite of the great proliferation of computers since 1946, this decision always seemed like a reasonable one to most people involved with computers, until very recently.

In spite of the fact that computers were built as numerical processors, a small group of computer scientists continued to explore the ability of computers to manipulate non-numerical symbols. Simultaneously, psychologists concerned with human problem solving sought to develop computer programs that would simulate human behavior. Over the years, individuals concerned with both symbolic processing and human problem solving formed the interdisciplinary subfield of computer science called artificial intelligence (AI). AI researchers are concerned with developing computer systems that produce results that we would normally associate with human intelligence. During the 1980's, several companies set up AI groups to develop practical applications. However, these efforts failed because AI programs were too costly to develop, were too slow, and didn't produce sufficiently practical results. AI programs were simply too complex to run on the computers that existed at the time. However, AI researchers continued to work in the universities and made steady theoretical progress. Meanwhile, the development of microelectronics technology resulted in a new generation of faster, more powerful, and relatively inexpensive computers. Today AI has once again emerged from the laboratories. Existing computer hardware, combined with significant theoretical advances in AI, has resulted in a technology whose time has come.

AI can be subdivided into three relatively independent research areas: natural language processing, robotics, and expert systems. In the first area, AI
researchers are concerned primarily with developing computer programs that can read, speak, or understand language as people use it in everyday conversation. This type of programming is commonly referred to as natural language processing. Another group of AI scientists is concerned with developing smart robots. The scientists are especially concerned with how to develop visual and tactile programs that will allow robots to observe the ongoing changes that take place as they move around in an environment. The third area of AI research, expert systems, is concerned with developing programs that use symbolic knowledge to simulate the behavior of human experts.

Edward Feigenbaum, a professor from Stanford University, has defined an expert system as "an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field." In the 1970s a group of workers from the Heuristic Programming Project at Stanford University, California, led by Professor Feigenbaum, built high performance decision making programs. In 1976 Edward Shortliffe from Stanford University wrote the MYCIN expert system to assist physicians in diagnosing infectious diseases [Firebaugh, 1988]. MYCIN was the first large expert system to perform at the level of a human expert [Harmon and King, 1985]. This expert system is a computer program designed to provide physicians with advice comparable to that which they would otherwise get from a consulting physician.
The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The "heuristics" are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision-making in the field. The performance level of an expert system is primarily a function of the size and the quality of its knowledge base. The general architecture of an expert system is illustrated in Figure 2.1. The main components in this architecture are the knowledge base, the explanation facility, and the knowledge acquisition facility. The knowledge-base component stores the heuristics knowledge obtained from a human expert. The explanation facility is responsible for explaining the reasoning process of the system. This facility responds to the user's inquiry (why and how). The acquisition facility helps the developer of the system (the knowledge engineer) enter the knowledge into the knowledge base. These components and other features are presented in the next chapter.

2.3.2 Who are the Expert and the Potential User?

Once a problem domain has been identified, the expert whose expertise will be modeled in the expert system should be selected. The bottleneck of developing an expert system is in finding a "good" expert. The report Developing Expert Systems [FHWA, 1988] suggests two main questions that should be asked to identify a "good" expert:

1. Is the candidate an expert in solving problems in the problem domain of interest and is he or she recognized as such by the potential users community? The need for the candidate to be an expert in the field is essential for the development of the expert system.
2. Is the expert available and willing to spend the time (perhaps months) that will be required to build, test, and field a working expert system? The expert must be dedicated to the successful development, testing and evaluation, and implementation of the system. The failure to identify such a person and obtain a firm commitment means that the expert system project should not be undertaken.

These two criteria besides other criteria presented in the next chapter were satisfied in selecting a human expert for the knowledge acquisition process during the development of our expert system, EXACT.

In developing an expert system, the knowledge engineer must define the user for whom the system is built. Defining the user of the system is crucial step in developing the system. This step helps the knowledge engineer to determine how detailed the system's prompts and conclusions should be in order to be understandable by the user. The potential user is a traffic practitioner who should have some background in the area of traffic-actuated control.
Figure 2.1. A Typical Architecture for an Expert System.
2.3.3 Expert Systems in Transportation

Recently, expert systems have been widely used in fields where judgment and experience play an essential role and where theory is inadequate to give a satisfactory solution to the problem. Researchers in the transportation field have recently implemented this technology as an appropriate tool for a variety of transportation problems. Takallou (1985) presents a three-dimensional cubic model of current knowledge-based expert systems (KBES) research in civil engineering. The x-axis of the model categorizes the research into particular branches of civil engineering. The y-axis of the model categorizes the "function" emphasized in the research. Finally, the z-axis categorizes the research by its orientation to implementation. The model shows the lack of ongoing research effort at KBES for all functions of transportation engineering. Since then, however, this technology has received substantial attention in the transportation field. Currently, several expert systems have been developed in different domains of transportation, such as facility design, disaster response planning, bus transit network planning, traffic operations and control, and pavement maintenance and rehabilitation.

Edmond Chin-Ping Chang [1987] developed an experimental expert system to assist users in selecting computerized software packages currently being supported by the Federal Highway Administration (FHWA). This study was performed to serve three purposes: 1) to test the feasibility of developing a small-scale traffic engineer knowledge-based expert system using a sample knowledge engineering tool, 2) to develop an alternative method of recommending computer programs for user-specified applications, and 3) to investigate a possible approach for implementing advisory expert systems to be operated in the IBM PC microcomputer environment. Chang describes how he developed a prototype expert
system using a commercially available knowledge engineering tool. He recommends that the expert-advisory-system-design concept of this prototype model be extended to assist practicing traffic engineers in selecting software packages to optimize traffic control strategies. Another experimental expert system was developed by Chang [1987] for recommending alternative left-turn phase selection on microcomputer systems. The goal of this study was to computerize left-turn phase selection by using artificial intelligence languages and knowledge engineering. This study investigates expert systems programming using PROLOG and INSIGHT 1 systems in the IBM microcomputer environment. The results of this study indicate that it is feasible to combine artificial intelligence and traffic engineering technologies for alternative traffic signal analysis. Chang presents a design process to formulate the expertise in a way that a computer understands. He suggests a decision table design and a flow chart to represent the knowledge. Such a representation was helpful to us in building the relationships of the main aspects of EXACT's knowledge that we acquired from our expert.

Besides Chang's expert system for selecting software packages, Zozaya and Hendrickson [1987] developed an experimental knowledge-based expert system to assist in traffic signal settings at isolated intersections. In contrast to existing computer aids, this system can be applied to intersections of highly irregular geometries. The system was written in the OPS5 expert system environment. The authors emphasize that numerous computer aids have been developed to guide engineers in selecting appropriate phase distribution and control strategies. However, a number of problems prohibit the useful application of these aids. According to the authors, "Designing the operation of traffic signals is not an algorithmic process. The experience and knowledge that the traffic engineer has
with the problem are important factors that affect the final solution." The authors emphasize the importance of experience in selecting traffic time settings which we address in the motivation of our research.

The Intersection Advisor is yet another prototype expert system developed to recommend geometric modifications to improve intersection operation [Bryson, Jr., and Stone, 1987]. During an interactive consultation the system asks the user for information regarding volumes, critical movements, geometry, and constraints on approach improvement. It then recommends the most efficient improvements for each approach by generating one of nearly 600 possible reports.

Richard and Brian (1988) examine the advantages that expert systems offer over more conventional forms of computer programming. They also suggest areas of application for which expert systems are likely to be successful, and they review several expert shells. They introduce the PC Plus expert system shell, used in our research, as a well-designed expert system that offers sophisticated approaches to solving complex problems.

The FHWA in 1988 published a report entitled "Developing Expert Systems." This document provides guidelines for the development, documentation, and distribution of microcomputer-based expert systems. It presents several sections to cover the process of developing an expert system, including knowledge representation schemes, inference engines, software tools, and verification and validation. The report also describes the basic elements of expert systems technology and its promising future in the transportation field. This report
was very informative and added tremendous knowledge to our understanding of expert systems.

Che-I Yeh et. al. [1988] describe the characteristics of knowledge-based expert systems (KBES) and suggest some applications that appear to have a high potential for development in the field of transportation planning and engineering. They state, "An expert system that performs like a human expert at an isolated signal set can reduce manpower needs and provide continuous day and night service. Most of all, such an expert system would provide the best quality of service if the knowledge base were acquired from the best experts and modified to local conditions." The article brings our attention to the different domains of transportation where expert systems can be used. In particular, it points out the significant contribution of this technology in traffic operations to which the problem of this research belongs.

Hadipriono and Carlos [1989] developed a powerful yet user-friendly CROPCAST OSU expert system to determine the crop yield production of a certain crop field. The study is based on the fact that heuristic assessments and decision-making in agriculture dominate much of agribusiness. CROPCAST is a PC Plus-built expert system. The authors used a majority of PC Plus features to make the system user-friendly and efficient. CROPCAST has four subframes besides the root frame. They represent the sources of information used to determine the crop yield that are acquired from the domain experts. The program has a sophisticated interface with databases and graphics. The authors' presentation of the PC Plus shell in this research was very helpful to us in designing EXACT. Although PC Plus is documented in a few manuals (e.g., User's Guide), learning about others'
experience with the shell saved us a long time that would otherwise have been spent in knowing the shell itself.

Seneviratne [1990] describes the application of a knowledge-based system (intersection safety management information system [ISMIS]) to resolve safety issues at intersections. ISMIS is a menu-driven system provides users with explanations for certain decisions, references, and measures available for remedying a particular problem. It also permits the user to perform an analysis of cost-effectiveness.

Faghri and Demetsky [1990] developed a prototype expert system, called TRANZ, for selecting appropriate traffic control strategies and management techniques around highway work zones. This expert system is derived from a literature survey on existing techniques and approaches for handling traffic around highway work zones and from interviews with selected experts in charge of the planning and design of traffic control strategies for work zones in Virginia. TRANZ's knowledge base consists of 141 rules. The authors tested TRANZ on 11 problems, and it gave 100% correct solutions. The testing process of TRANZ presented in this article was helpful for us in testing EXACT.

The literature has shown that expert systems have been gaining acceptance in the transportation field. The Federal Highway Administration (FHWA) is beginning to consider this technology for its potential application in highway engineering. Although we believe that expert systems should be based on human expertise, we found that the knowledge of some developed expert systems was obtained from written documents, such as reports and manuals. In the system developed in this
research (EXACT), a human expert in the field of traffic-actuated control was the source of knowledge.

In conclusion, several points can be noted from the literature:

– There are no specific guidelines for the design of actuated signal controls at isolated intersections. Most of the state transportation agencies have established their own guidelines. As previously mentioned, techniques, including optimization and simulation, do not take all the factors of the selection process into consideration because of the difficulty of quantifying these factors, such as pavement condition, abnormal geometric configurations, and drivers' behavior. This makes the expert system approach appropriate for the problem of this research.

– Several studies have emphasized the role of the traffic engineer's expertise in the design process, which again confirms our approach to this research.

-- Expert systems technology has received wide attention in the transportation engineering discipline when expert judgment is required. This attention was one of the factors that encouraged us to implement expert systems technology in this research.

Table 2.1 presents several expert systems that have been developed in the transportation field.
Table 2.1. Some Developed Expert Systems in the Transportation Field.

<table>
<thead>
<tr>
<th>Expert System Name</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>OVERDRIVE</td>
<td>OVERlay Design heuRIstic adVisEr to design the structural thickness of asphalt concrete pavement overlays [Stephen, 1987]</td>
</tr>
<tr>
<td>SCEPTRE</td>
<td>Surface Condition Expert System for Pavement Rehabilitation Planning [Stephen, 1987].</td>
</tr>
<tr>
<td>TOP_ADVISOR</td>
<td>Expert system to assist in the interactive graphic transit system design process [Janarthanan, 1988].</td>
</tr>
<tr>
<td>TRANZ</td>
<td>Expert System for Traffic Control in Work Zones. [Faghri and Demetsky, 1990]</td>
</tr>
<tr>
<td>ISMIS</td>
<td>Knowledge-Based System for Managing Intersection Safety [Seneviratne, 1990].</td>
</tr>
</tbody>
</table>
CHAPTER III
DEVELOPMENT STAGES OF EXACT

This chapter has two objectives. First, the expert system employed in this research is introduced. What the expert system is and what makes it the appropriate tool to approach the research problem will be discussed. Second, the product of this research, an expert system EXACT (an acronym for "EXpert System of Actuated Control for Traffic at Isolated intersections"), is described according to its stages of development.

3.1 A Knowledge-Based Expert System Approach

Expert systems is a branch of a technology often called Artificial Intelligence (AI). The objective of AI is to make computers capable of displaying behavior that is considered intelligence when observed in humans. AI involves a few major areas, including robotic, natural language processing, and expert systems. Our concern is with expert systems.

In the last few years, expert systems have won the most attention from the mainstream data processing community. Many definitions of expert systems have been attempted. According to Pedersen, expert systems are computer programs that give the appearance of human-like reasoning for problems ordinarily requiring expertise [Pedersen, 1989]. Edward Feigenbaum explains an expert system as:

an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of
the expertise of the best practitioners in the field. The knowledge of an
expert system consists of facts and heuristics. The facts constitute a body of
information that is widely shared, publicly available, and generally agreed
upon by experts in a field. The heuristics are mostly private, little-discussed
rules of good judgement (rules of plausible reasoning, rules of good
guessing) that characterize expert-level decision making in the field. The
performance level of an expert system is primarily a function of the size and
the quality of a knowledge base it possesses [Feigenbaum, 1981].

Another definition of an expert system [Waterman, 1985] is the collection of
programs that solve problems in the domain of interest. Because this collection
contains both a problem-solving component and a support component, it is called a
system rather than just a program. Since the purpose of this support component is
to help the user interact with the main program, the support component may include
sophisticated debugging aids to help test and evaluate the program's structure. It
also includes friendly editing facilities to help the experts modify knowledge and
data in the expert system, and an advance graphics facility to help the user input
and read information as the system is running.

The main players in the development of an expert system are the domain
expert, the knowledge engineer, and the expert-system-building tool. The basic
relationships among these players are presented in Figure 3.1.

The domain expert can be defined as a knowledgeable person with a
reputation for producing good solutions to problems in a particular field. Using
his/her judgment, rules of thumb, and educated guesses, the expert can make the
search for a solution more efficient, and the expert system can embody these
problem-solving strategies. Although an expert system is known to be modeled
Figure 3.1. The Key Players in an Expert System Development.
upon the knowledge of one or more human experts, it may also embody expertise
from other sources, such as books, manuals, and journal articles.

The knowledge engineer plays the essential role of interacting with the
domain expert in order to obtain the necessary knowledge to build an expert
system. He or she should know the foundations of expert systems in computer
science. The knowledge engineer also interviews the expert(s), organizes the
knowledge, identifies the relationships among the variables that provide the
knowledge, and decides how the knowledge should be represented in the expert
system.

The expert-system-building tool is the programming language that the
knowledge engineer uses in building the expert system. Conventional computer
programs written in, for example, Fortran and Basic are different from those of
expert systems. Although such programs can be interactive and contain judgment
and rules of thumb, they are not expert systems. Expert systems can be
distinguished from conventional programs in the following ways:
- Expert systems contain symbolic knowledge, not numerical data as in
  conventional programs.
- Expert systems use heuristic in a specific domain to improve the efficiency of
  search.
- The knowledge base in expert systems is separated from the mechanism which
  applies such knowledge (inference mechanism).
- Expert systems are highly interactive; as a result, the user can stop the program at
  any time during a consultation to ask how/why questions.
Another way in which expert systems differ from conventional programs is that expert systems might make mistakes. While conventional programs are designed to produce an exact and correct answer, expert systems are designed to simulate the behavior of a human expert, usually producing correct answers but sometimes producing incorrect ones. The term "tool" usually stands for both the programming language and the support environment used to build the expert system.

The user is the person who uses the expert system once it is developed. The user could be a tool builder debugging the expert-system-building language, a knowledge engineer refining the knowledge base, a domain expert adding new knowledge to the system, or an end-user relying on the system for consultation.

The typical architecture of an expert system is shown in Figure 3.2. Knowledge base and the inference mechanism are the critical components of any expert system once it has been designed. The knowledge base of an expert system consists of the rules and the facts of a particular domain of knowledge. That is, a knowledge base component holds all the expertise relevant to the problem that one wants to be solved by the expert system. The inference mechanism (engine), the other critical part of an expert system, is responsible for inference and control. It has the ability to control the order in which rules are examined, to select the rule with which start, to check the next rule, and to decide when a conclusion has been found, when to ask the user for more information, and when to give up.

Explaining the system's reasoning and justifying its conclusions are the main functions of the explanation facility. It can usually answer the user's questions of why and how a particular conclusion has been reached. It is sometimes called an
explanatory interface module. This facility distinguishes expert systems from conventional programs because it makes expert systems more interactive with the program. In other words, the user can stop the program at any stage during the session and ask the computer why this piece of information is required or how such a conclusion is reached.

The knowledge-acquisition facility helps the knowledge engineer transfer the knowledge from the expert or other sources to the knowledge base. This knowledge may be formulated into rules to solve problems. This facility includes a rules editor. In more sophisticated systems it may include a syntax checker and provide ways for checking for a conflict with a rule.

In this research, expert system technology is used as a tool. The pertinence of this technology to the research problem is described in the following paragraphs.
Figure 3.2. The Typical Architecture of an Expert System.
3.2. The Knowledge-Base Expert Systems for Traffic Actuated Control at Isolated Intersections

To date, there is no specific guideline for the selection of the actuated control alternative, the time settings, and the detector placement. The absence of such guidelines can be attributed to the complexity of the problem. That is, the numerous types of geometry, wide ranges of traffic volumes, drivers behaviors and expectations, traffic compositions, and other factors make the problem so complex that it is difficult to determine specific guidelines that can handle the problem appropriately.

Presently, the preference among alternatives is largely subjective and speculative. The type of actuated controller (i.e., full-actuated or volume-density controller), the time settings, and detector types and locations that should be used at a particular intersection with specific traffic conditions all these are subjective decisions. Traffic professionals have used a trial-and-error technique to make such selections. The rapid change in state-of-the-art actuated control equipment has made such equipment more sophisticated, with many features that provide the traffic engineer with a variety of choices.

The behavior of drivers tremendously affects the selection of time settings in the controller unit. The selection of passage time, for instance, for a controller in the downtown area is different from that in a residential area. Drivers in the downtown area are usually more aggressive and hurried; therefore, the passage time should be kept as short as possible. In contrast, drivers in residential areas tend to be slower; hence the passage time should be kept as long as possible. But how
"long" is long and how short is "short"? The experts in the field answer this question subjectively. Using their judgment as well as some rules of thumb, experts can select an appropriate passage time for a specific intersection in a particular location to ensure efficient traffic operation. The same discussion holds for other time settings.

The presence of other factors, such as pavement problems, a driveway around the intersection, and irregular geometry, requires additional attention from the traffic engineer to decide properly where to place detectors and what features should be set into the controller unit in order to operate the signal efficiently. The stopline location, for example, affects the placement of the detector. For some geometric considerations the stopline is located far away from the curb line. Having decided to use a loop design, the traffic engineer must decide how long the front of the loop should be extended ahead of the stopline.

In summary, selecting the actuated-control type, the time settings, and detector types and locations involves a substantial amount of experience, judgment, and experts' rules of thumb, which in turn makes the problem heuristic in its nature. Consequently, expert system's technology should be a promising approach to the problem.

3.3 Stages of EXACT's Development

Five highly overlapping phases describe any expert system development:

1. Identification: During this stage the important features of the problem should be defined by the knowledge engineer and the expert. These features
include identifying the problem itself, the participants in the development process, the required resources, and the objectives behind the system's development. At the beginning of this stage the knowledge engineer should describe clearly to the expert the problem and the main goals in building the expert system. It is very critical to have the expert understand the problem along with his/her fundamental role in the development process.

2. Conceptualization: During this stage the problem concepts and relations between such concepts are needed to describe the expert's problem-solving process. The problem can be divided into subproblems to make it more convenient for next stages of the development process.

3. Formalization: This stage involves expressing the concepts and relations from the previous stage in a specific way to be accepted by the development tool. This building tool could be an expert system language or a shell. The knowledge engineer should have some ideas regarding the appropriate tools for the underlying problem by the time formalization begins. Some problems require rule-based tools while others require object-oriented tools.

4. Implementation: In this stage the formalized knowledge from step 3 should be turned into a workable computer program. The knowledge engineer should start prototyping a piece of the knowledge to check the structure and the logic of the program from the earlier phases of the system development. This also will help to check the effectiveness of the design decisions made at the beginning.
5. Testing: During this stage the knowledge engineer and the expert evaluate the performance of the prototype program and revise it as necessary. The domain expert plays an essential role in this stage by making suggestions to revise the system and the solution path. The prototype should be run over a few cases to uncover gaps or inconsistency in the program structure.

Now a very detailed description of the development of EXACT is presented in its various stages: variable identification, shell selection, knowledge acquisition, knowledge representation, and testing and evaluation.

3.3.1 Define the Variables Pertinent to the Study

Currently, more than half of all vehicular trips take place in urban areas. Most metropolitan areas are encountering traffic problems. Urban traffic control strategies, including effective signal control at signalized intersections, can be aided through experienced engineering design before the field implementation.

Over the years, actuated controllers and traffic responsive system have been substantially installed. The rapid changes in state-of-the-art, traffic-actuated equipment, from mechanical to solid-state devices, have improved the implementation of such equipment at signalized intersections. As a result, substantial research has been directed toward the interrelationship between such technologically advanced equipment and its operation in these locations.
Efforts were made to extensively review the current practice and relevant research in traffic-actuated control to define the major variables affecting the selection of traffic-actuated controllers, time settings, and detector locations and types at isolated intersections. It has been found that these variables or factors can be related to three categories:

1. Intersection Geometry
2. Traffic Characteristics
3. Time Settings

A wide range of geometric configurations can be found at isolated intersections. Intersections can be distinguished geometrically through their number of approaches, width of lanes, number of lanes, and grade of approach. After a comprehensive survey of most typical geometric layouts, twenty eight geometric configurations have been covered in this research, as shown in Figure 3.3. These configurations range from one-lane approaches to six-lane approaches. All kinds of movements were considered such as:

1. Through (straight) traffic
2. Left-turning traffic
3. Right-turning traffic
4. Shared-lane traffic
5. Double left-turning traffic

These movements alter the detection design, in terms of detector type and location, at isolated intersections. The left-turning movement, for instance, needs a special design considering the signal phase, protected or permitted. The most
Figure 3.3. The Geometric Configurations Covered in this Research.
typical intersection type is the four-legged intersection. However, there are also T-intersections, five-legged intersections, and intersections with different angles between their approaches. Another geometric feature that may affect traffic control design at isolated intersections is the width of lanes. The width of lanes ranges typically from 9 ft. to 20 ft. The width dramatically influences the detector layouts and detection type. For instance, if the point-detection system is to be used, the number of probes that should be placed will depend on the width of the lane(s).

When the traffic engineer is faced with more than one lane in a particular approach, two questions are raised: Is it possible to cover a group of lanes with one detector? and How effective is it to use a loop system instead of a probe system?

The grade of approach at a signalized intersection has a direct effect on time settings, in particular, the passage time. Drivers on a downgrade tend to be faster than those on an upgrade.

At the preliminary stages of this research the above variables were defined based on literature and other sources such as professional manuals. However, when the knowledge engineer spoke with the expert during the knowledge-acquisition stage, the knowledge engineer updated the list of variables. Table 3.1 exhibits the preliminary list of variables.
Besides geometric configurations, a traffic controller must consider certain characteristics of the traffic at each isolated intersection. The literature on this subject mentions volume, speed, and traffic movements as the primary characteristics. Volume refers to the number of vehicles passing a given point per unit of time. The fluctuations of traffic volume (demand) throughout the day at an isolated intersection justify the implementation of a traffic-actuated type of control. This variable has a significant impact on the design configuration of detectors. Heavy left-turning volume, for example, may indicate the necessity of loop detector at a specific location. Speed, another traffic characteristic, is responsible for defining the type of approach (low or high speed approach), which drastically affects the whole design of actuated control. Similarly, traffic movements play a significant role in actuated-control design. A through movement, for instance, has different features reflected on the detection design from a left turning-movement.

Table 3.1. The related variables from the literature.

<table>
<thead>
<tr>
<th>Category</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric Features</td>
<td>- Number of approaches</td>
</tr>
<tr>
<td></td>
<td>- Number of lanes</td>
</tr>
<tr>
<td></td>
<td>- Width of lanes</td>
</tr>
<tr>
<td></td>
<td>- Grade of approach</td>
</tr>
<tr>
<td>Traffic Characteristics</td>
<td>- Volume</td>
</tr>
<tr>
<td></td>
<td>- Speed</td>
</tr>
<tr>
<td></td>
<td>- Movement</td>
</tr>
<tr>
<td>Time Settings</td>
<td>- Passage time</td>
</tr>
<tr>
<td></td>
<td>- Initial green</td>
</tr>
</tbody>
</table>
Having considered geometric configurations and traffic characteristics, a traffic practitioner must now select appropriate time settings, such as passage time, initial green time, and maximum green time. Passage time is the time required for a vehicle to travel from the detector to the intersection either without losing the green light, or losing the green light within an allowable gap. Passage time has been the subject of many studies as a variable influence upon the efficiency of traffic signals at isolated intersections. Bullen [1988] cites the most critical variable in a vehicle-actuated signal as vehicle extension (passage time). Tanroff and Parsonson [1979] refer to a few variables, including speed, passage time, and volume. The passage time is created normally after the initial green time, the time required for a standing queue between the detector and the stopline to get started and clear the intersection. Another time setting is the maximum green time, a preset limit of the green time. After the maximum green time has elapsed, the yellow indication comes on.

3.3.2 Implementation Tool (Shell Selection)

There are three different types of software tools available for developing expert systems:

1. AI Programming Languages
2. Knowledge Engineering Environments
3. Expert System Shells

AI languages are computer programming languages which have special facilities, such as an acquisition facility and an explanation facility, for expert systems programming. Two popular AI languages are used today. LISP language
was developed in the 1960's and has been used for artificial intelligence research work in the USA. The other language is PROLOG, developed much more recently in Europe. These languages have their own features and are very suitable for expert systems development. However, they require a very skillful programmer with a strong background in computer science, especially in the AI domain.

Knowledge engineering environments, including KEE, ART, and knowledge craft, are other tools for building expert systems. They are the "Rolls Royce" of expert systems programming [Barrett and Beerel, 1988] and are expensive to run. Environments require programmers of the first rank.

Expert systems shells are the most desirable tool for developers who are not computer science specialists. A shell is a ready-made expert system with no knowledge. Because of their wealth of features, shells are widely used in a variety of domains. The majority of commercial expert system shells are based on rules. Shells' ease of use, availability, and ability to run on personal computers make them the most popular tool for building expert systems. However, shells have their limitations. It is difficult sometimes to find a shell matching your needs. Moreover, not all shells provide developers with such facilities as interaction with external programs and graphics capabilities. The higher the price of the shell, the more features it can offer. Figure 3.4 summarizes the typical features of expert system shells, AI programming languages, and knowledge engineering environments [Barrett and Beerel, 1988].

Deciding on the shell to be used as the development tool in this study is an important step. A survey of the available shells in the market to select the most
suitable and most reasonably priced one for the research problem was done.

Specific criteria were used:

1. The shell should be able to do what we want. The knowledge can be represented as rules. Therefore, a rule-based shell is needed. It must have an explanation facility.
2. To meet research needs, the shell should provide special features, such as a calculation capability and the ability to interface with external programs like graphics.
3. The cost of the shell should not be more than $4000. It should not need complex hardware to run. That is, it can run on PC machines (IBM and IBM compatibles) with a reasonable RAM memory. A support service and clear documents should be provided with the selected shell.

After a long and comprehensive survey, an expert system shell called a Personal Consultant Plus (PC Plus) shell, from Texas Instruments in Dallas, Texas, was selected to be the development tool in this research. PC Plus has been widely used for expert systems development. PC Plus is a highly functional tool for developing expert system applications. It offers a sophisticated frame structure for handling multidimensional problems, techniques for imposing rule-order strategies, the ability to extend and customize the consultation environments, large rule capacity, and the ability to address almost 2 megabytes of RAM. PC Plus is well suited for rapidly creating prototypes.
Figure 3.4. The Typical Features of Expert System Development Tools
(Barrett and Beerel, 1988)
### 3.3.2.1 PC Plus Features

PC Plus includes many powerful and helpful features:

- A highly interactive environment for development and testing
- Debugging and value-checking aids
- Access to external DOS files and databases
- The ability to display graphics
- A mechanism for handling uncertainty both from the developer and from the end user
- An ability to explain in English why the system is asking for information and how it reached a conclusion
- A comprehensive rule-entry language that is similar to English
- A window-oriented interface with extensive on-line help
- A full-screen editor
- Meta-rules for sophisticated rule control
- The ability to extend a knowledge base through the use of user-defined Lisp functions
- A frame capability that allows the knowledge base structure to be divided into logically different, but related, segments
- Additional means (other than inferencing and prompting) to evaluate and set parameter values
- The ability to run on IBM Personal Computer AT (and AT compatibles)
- A delivery system. A delivery version called a run-time version can be used to distribute the developed expert system.
The shell provides mainly backward chaining inference engines as well as a fair amount of forward chaining. Knowledge representation can be done through:

- Frames and Parameters (with inheritance)
- Production Rules
- Meta Rules
- Access Methods

A PC Plus knowledge base always contains at least one frame, the root frame. As a developer adds knowledge to the knowledge base, he/she can also create additional frames, or subframes. The frame, the basic structure of a PC Plus knowledge base, is a collection of information. Inside each frame are the knowledge parameters, structures that identify or contain pieces of information the PC Plus needs to arrive at a conclusion. A frame groups the parameters and production rules. In this research the production rules were compiled from the knowledge acquired from an expert in the form of IF-THEN statements.

PC Plus involves three activities: DEVELOP, BUILD, and CONSULT. The DEVELOP activity enables the knowledge engineer to start developing an expert system through constructing the knowledge base. The BUILD activity develops a run-time version that can be used without accommodating the PC Plus shell. The CONSULT activity starts a consultation with the knowledge base.

3.3.3 Knowledge Acquisition

Knowledge must be acquired from a human expert and other sources of expertise in order to develop an expert system. This process requires that the knowledge engineer and the expert to work together on the knowledge base. Two major steps are involved in this process:
1. Selecting an expert
2. Obtaining knowledge from the expert.

3.3.3.1 Selection of an Expert

Currently there are no clear-cut criteria by which an expert can be defined, although most recent expert systems are human-based. It is strongly preferable to find a person who actually makes the decisions in traffic-actuated control at isolated intersections on a day-to-day basis and is associated with a practical, not a supervisory or theoretical, kind of job. Other possible criteria include the following:

1. The expert should be recognized by colleagues as making good decisions.
2. The expert should be reasonably articulate in explaining how to reach conclusions.
3. The expert should have at least five years of practical experience in the area of traffic-actuated control at isolated intersections and should still be working in this area.
4. The expert should be cooperative and have sufficient time to be committed to working with the knowledge engineer.

Fortunately, a very well-qualified expert was found in the City of Columbus's Traffic Division in Columbus, Ohio. Besides the above conditions, David Krier (a member of the Institute of Transportation Engineers) has a B.S. in civil engineering with a transportation major from the Ohio State University, and he has been involved in the problem domain for about ten years. He is responsible mainly for signal timing, detector installation, selection of actuated equipment, and other control issues at isolated intersections in Columbus. His interest in the idea of
expert systems made him very cooperative and supportive during this research. Professor Zoltan A. Nemeth was instrumental in arranging contact.

### 3.3.3.2 Our Expert's Criterion of Design

The expert we relied on in this research has his own criterion of expertise in the design of signal control at isolated intersections. This criterion is simply based on the following concept: "Not to keep a vehicle more than two cycles". That is, in the worst situation a vehicle should clear an intersection in the first two cycles from the time it joins a queue of vehicles (a cycle is a complete sequence of signal indications). David Krier's approach of design can be described as snappy.

The expert relies heavily on his judgment of drivers' behavior, which he considers as the major factor affecting his designs. Understanding such behavior makes it easy for him to select the appropriate detectors and signal timing parameters matching the needs of a specific group of drivers. The number of drivers in a residential area, for instance, consists of elderly and family drivers. Such a population needs a different design from that in a downtown area.

To exemplify the expert's snappy design, let's consider the passage time parameter as an example. At the end of the knowledge acquisition stage, the knowledge engineer summarizes the information concerning passage time, as shown in Figure 3.5. The figure shows that the selection of a passage-time value depends upon grade, speed, and the type of area where an intersection is located. For a down-grade approach, a downtown area, and a speed limit of 35 mph, the expert recommends a range of 1.5 to 2.0 seconds. He prefers the lowest value in this range, 1.5 seconds, to be set into the controller unit. From the expert's judgment
and experience, the difference of 0.5 seconds affects the perceived speed of the signal's performance.
Figure 3.5. The Passage Time Values Recommended by the Expert.
3.3.3.3 Acquiring the Knowledge from the Expert

Selecting the expert begins the knowledge-acquisition phase. The goal at the early stage of this phase is to obtain enough knowledge to build a prototype system. This prototype was the launching point in developing the system.

The knowledge-acquisition process in this research has gone through three major phases, depicted in Figure 3.6. The three phases are:

1. Discussion
2. Capture
3. Organization

The discussion phase was the process of describing clearly to the expert and in detail the problem and the goals of the study and making him aware of his vital role in developing the expert system. The expert's problem-solving strategy was clarified in this phase. The capture phase involved the process of documenting the expert's major concepts and noting their relationships. In the organization phase we ordered the knowledge and prepared to construct it as rules. These three phases are discussed in depth in the next sections.

3.3.3.3.1 Discussion

At the beginning of this phase, a full description of the problem was presented by the knowledge engineer to the expert. The knowledge engineer then described the characteristics and the goals of the research so that the expert would be very well informed about the subject. The expert was introduced to expert
systems technology and given a brief idea regarding its promising role in the research. The expert's significant role in the research was stressed.

Once the expert was familiar with the research goals, he described verbally the key aspects of the problem and then readily suggested how to obtain the desired knowledge. As Johnson states [1983], "The paradox of expertise: the more proficient an expert becomes the less they have to think about what to do."

In general an expert may have little experience in using words to describe his reasoning process. Yet, generating clear questions to the expert will help him be specific. Therefore, the goal of the capture phase was to encourage the expert to provide expertise verbally. The immediate output of the discussion phase is typically in the form of written notes and diagrams depicting the main aspects suggested by the expert.

3.3.3.3.2 Capture

The capture phase is the heart of the knowledge-acquisition process. In this phase the main aspects of the problem and the relationships between such aspects are determined. Figure 3.6 details the knowledge-acquisition process. Two basic elements form this phase:

1. Interview Sessions
2. Observation

Although interviewing is the most familiar technique of knowledge acquisition, there is no one method to perform it. The knowledge engineer might ask questions or prepare specific case studies and ask the expert to deal with them in front of the knowledge engineer. Documentation of the interviews can be done
through recording the conversation or writing down notes. In this research, interviewing comprised four steps:

a. Specific questions and answers
b. A review of literature and current practices
c. Case studies
d. Resolution of conflicts.

First, a list of questions was prepared by the knowledge engineer, and the expert was asked to answer these questions during the interview. The interview started with general questions, such as:
- What type of actuated control do you use most often at isolated intersections in Columbus?
- What are the major factors affecting your selection?
- What detectors do you employ?
- Do you follow specific procedures to design signal control?
- Does experience play an essential role in your design?

When the interview was over, the knowledge engineer reviewed the expert's answers and carefully analyzed them to determine the major points. Following this interview, a new list of questions was prepared for the next interview. The new list contained more specific questions than those in the previous list. Most of these specific questions were based on the expert's past responses. For instance, the expert responded to the first question that he uses full-actuated control. According to this answer, the knowledge engineer generated the following questions during the next interview:
- Why full-actuated only?
- Why don't you use a volume-density controller?
Figure 3.6. The Knowledge-Acquisition Process.
- Does semi-actuated control work?
- What are the disadvantages of volume-density versus full-actuated controllers?
- What feature do you use with a full-actuated controller?
- Do you always use a full-actuated controller? If not, when and in what cases?

Again the knowledge engineer reviewed the expert's answers and formed a new list of narrower questions for next interview, and the process continued.

Another side of interviewing phase is to review past designs made by the expert. Real-life cases designed by the expert are studied and discussed by both the expert and the knowledge engineer. This is a very informative step since the knowledge engineer becomes familiar with the decision-making process of the expert and explores new aspects of the problem. An additional practical benefit is that new factors the expert used in his design are found and added to the variables list of the research. The stopline location, for instance, was found an important variable affecting the design of the detection system at isolated intersections.

Besides real-life cases, the knowledge engineer designs several hypothetical case examples ranging from easy to fairly difficult and asks the expert to design signal controls for them. The knowledge engineer then examines the expert's work and identifies all the factors used by the expert in the solving process.

The most interesting part of this step is noticing the different approaches of the expert in designing different cases. That is, some cases need different approaches of design and involve distinct information from others. When these different approaches are discussed, the knowledge engineer can learn the problem-solving strategy of the expert, thereby obtaining a wealth of knowledge.
During the interview process the knowledge engineer should note any problems in the expert's logic. For example, the knowledge engineer may observe occasionally that the expert gives conflicting answers for similar situations. Such conflicts are resolved by presenting them to the expert for explanation or revision. In many cases these conflicts help the knowledge engineer to learn a new idea or a new direction in the course of the research.

Besides interviewing the expert, it is beneficial to watch him at work, in what we call the observation process. The knowledge engineer should document this work and then ask the expert for a verbal commentary. Later, the knowledge engineer should carefully analyze and summarize the expert's work.

For instance, our expert usually makes daily trips to several isolated intersections in the city in order to redesign the signal's timing or the detection systems. Joining the expert on these trips for a few months during the research, the knowledge engineer recorded everything the expert did. On each field trip the knowledge engineer and the expert spent at least ten minutes discussing pertinent issues, such as how to observe traffic problems and how to solve them quickly.

3.3.3.3 Organization

Now we have obtained a body of knowledge that needs to be organized. We started the organizational phase by forming and answering several questions:
- What factors or concepts directly impact our goal of design that expert uses?
- How does the expert express the values of these concepts? (Define the numerical and the symbolic values)
- What questions does the expert ask during the problem-solving process?
- What conclusions has the expert made?

The answers to these questions helped us to diagram the expert's knowledge, as discussed in the next section:

At the end of this phase the original list of variables, called parameters in PC Plus and shown in Table 3.1, was updated; the updated list is presented in Table 3.2. During the knowledge-acquisition phase, the knowledge engineer has been writing down the expert's knowledge in a tentative IF-THEN structure and producing a large number of rules. Figure 3.7 presents a few of these rules. Their common background is that they include the actions that the expert may take in real-life problems. That is, they form the problem-solving methods of the expert for large number of real cases.
1. If approach speed is greater than 35 mph then dilemma zone technique should be used.

2. If the left-turning volume is greater than 80 vehicle in 15 minutes then a left-turn phase is recommended.

3. If the speed limit is equal or less than 35 mph and the lane is for through traffic only then use a point detection design and set the detector 110 ft. back from the stopline.

4. If the speed limit is equal or less than 35 mph and the lane is for protected left-turn only use a presence detection design (i.e. Loop system) and the loop should be placed at the stopline.

5. If the stopline is over 20 ft. from the curb line then you may extend the front of the loop 20 ft. a head of the stopline and back of the loop 20 ft. behind the stopline which makes the loop 40 ft. in the length.

6. If left-turn phase is protected only then presence detection should be used to avoid false calls during light traffic conditions when a driver may decide to disobey the signal, especially during night time.

7. If pavement is in very poor condition for presence detection design then non-lock operation may be sacrificed and point detection is used and placed behind the poor section of the pavement.

8. If loop detector is used then the minimum width for the loop is 4 ft. (or as recommended by the manufacture), and the maximum width is 6 ft. (or as recommended by the manufacture), and maintain 2 ft. minimum from lane line to avoid adjacent lane interaction.

9. If the product of left-turning volume and the conflicting through volume during a peak hour is greater than 100,000 then a protected left-turn phase is needed.

10. If an approach has several lanes and probe detection is used then there should be one probe set or combination of probe sets per lane.

Figure 3.7. A Sample of Rule Draft obtained at the earlier stage of knowledge Acquisition.
These rules, in turn, form the foundation of the knowledge-representation stage, explained in the next section, in the development of EXACT.

Table 3.2. The updated variables' list.

<table>
<thead>
<tr>
<th>Category</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric Features</td>
<td>- Number of approaches</td>
</tr>
<tr>
<td></td>
<td>- Number of lanes</td>
</tr>
<tr>
<td></td>
<td>- Width of lanes</td>
</tr>
<tr>
<td></td>
<td>- Grade</td>
</tr>
<tr>
<td></td>
<td>- Stopline</td>
</tr>
<tr>
<td></td>
<td>- Turning Radius</td>
</tr>
<tr>
<td></td>
<td>- Curbline</td>
</tr>
<tr>
<td>Traffic Characteristics</td>
<td>- Volume</td>
</tr>
<tr>
<td></td>
<td>- Speed</td>
</tr>
<tr>
<td></td>
<td>- Movement</td>
</tr>
<tr>
<td></td>
<td>- Driver's behavior</td>
</tr>
<tr>
<td>Time Settings</td>
<td>- Passage time</td>
</tr>
<tr>
<td></td>
<td>- Initial green</td>
</tr>
<tr>
<td></td>
<td>- MAX I</td>
</tr>
<tr>
<td>Controller Features</td>
<td>- RECALL ON/OFF</td>
</tr>
<tr>
<td></td>
<td>- MEMORY ON/OFF</td>
</tr>
<tr>
<td></td>
<td>- Extension</td>
</tr>
<tr>
<td></td>
<td>- Delay</td>
</tr>
<tr>
<td>Others</td>
<td>- Pavement condition</td>
</tr>
<tr>
<td></td>
<td>- Driveway presence</td>
</tr>
<tr>
<td></td>
<td>- Construction</td>
</tr>
<tr>
<td></td>
<td>- Equipment failure</td>
</tr>
</tbody>
</table>
3.3.4 Knowledge Representation and Building the Knowledge Base

Among the methods of representing knowledge is the rule-based technique, which is used in this research because of its suitability for the nature of the problem. In other words, the knowledge obtained from the expert can be organized into rules. The body of a rule consists of several conditions, several consequences, and possibly alternatives and negations (i.e., "OR" and "NOT"). For example:

IF the problem is DESIGN and street is MAJOR or MINOR and movement is THROUGH and speed is > 35 mph
THEN the recommended detector type for this lane is a PROBE detector.

By the end of the knowledge acquisition phase, crude IF-THEN rules containing the expert's knowledge were available. These rules were then divided into three categories: Detector, Signal Timing, and Controller Features. Each category has a homogenous group of rules. Next, each group of rules in every category was separated into subgroups. The detector location, for instance, is a subcategory for the category Detector and has its own subgroup of rules. This categorization, shown in Figure 3.8, helped us to break up the knowledge obtained from the expert and to prepare it for the representation phase.

The categorized knowledge from the knowledge-acquisition stage was decomposed into linked key aspects. From these aspects, we drew a diagram to illustrate the relationships among the main aspects of our experts' solving process. Figure 3.9 displays one diagram for a small piece of information obtained from our expert concerning the selection of the detector type.
Figure 3.8. The Categorization of the Expert Knowledge.
Figure 3.9. A Sample Diagram for a Small Piece of Knowledge Obtained from the Expert.
At the top level of this diagram, "problem" means the type of problem being asked (a problem in either design or operation). As we proceed down the diagram, we find different levels of input until the goal is reached, in this case the selection of a type of detector. The diagram shows several inputs, including street type (major or minor), speed, and movement. These inputs must be defined before one can reach the goal. At any level of input there could be more than two branches. Speed, for instance, has two branches, but movement has twenty eight. The LATR code stands for an approach with two lanes, a left-turn lane and a shared through and a right shared lane. Before reaching the goal, information is required, such as the type of left-turning phase (protected or permitted), and the percentage of left-turning traffic of the approach volume.

At this point, all the knowledge obtained from the expert is contained in diagrams connecting the main aspects of the problem (see Appendix C for more diagrams). Now the time has come to translate these diagrams into a rule-based structure, called workable or production rules, that can be used in the computer shell. In PC Plus these production rules must be translated to Abbreviated Rule Language (ARL), the language in which the user enters PC Plus rules. However, before entering these rules into the computer, FC Plus requires the developer to structure the program through frames, main and subframes, and parameters. Having carried out such a structure, the knowledge engineer can enter the formatted rules. Simply, each rule in the ARL format has parameters in the premise part, the left hand side of the rule, connected by logic operators, such as AND, OR, and NOT. In the action part, the right hand side of the rule, there must be at least one goal parameter. All parameters in both sides of an ARL rule must have single or multiple values. Such values must be defined in the properties of the frame to which
the ARL rule belongs. This process will be discussed intensively in the following section.

3.3.5 Building EXACT Knowledge Base

The frame is the basic structure of a PC Plus knowledge base. A knowledge base must have at least one root frame and can contain one or more subframes. If a knowledge base is large or complex, the knowledge engineer may want to create one or more subframes. However, when subframes are used, two issues must be considered: inheritance and instantiation.

Inheritance gives subframes access to parameters in the root frame. The root frame is known as the parent frame; the subframe created is a child of the root frame. The subframe has its own properties, parameters, rules, and other characteristics. The concept of child and parent frames is very important in PC Plus knowledge base development, because a child frame inherits the use of parameters from its parent.

Now suppose we have a hypothetical knowledge base as shown in Figure 3.10. The two child frames A and B have access to the parameters in the root frame, but neither has access to the other's parameters. If subframe D is added to subframe C, D will have access to the parameters in the root frame and in its own parent frame, namely C. Neither the root nor the parent has access to the new subframe's parameters. Conversely, frames have access to rules in descendent frames, but not in ancestor frames. A frame's ancestors include all the frames that are in a direct line to the root frame. A frame's descendants include all the frames that are in rules in descendant frames that activates the mechanism from instantiating subframes.
Figure 3.10. The Relationships of Frames in a Hypothetical Knowledge Base.
Instantiation means the activation of a frame during a consultation. Instantiation does not happen automatically, but by design. The frame created during the development of the knowledge base is considered a static representation of knowledge (rules and parameters) and structure. When PC Plus instantiates the frame during a consultation, the frame is given a dynamic, concrete reality.

Generally speaking, the knowledge base has parameters and rules to cover all possible cases, but as soon as it determines the characteristics of the client, it uses only the parameters and rules needed for that particular situation.

In this research the EXACT knowledge base has four frames, one a root frame and three subframes. The names of the frames and the inherited relationships among them are illustrated in Figure 3.11(a).

The frame structure shown in the previous figure results in the following scope:

* Frame TRAFFIC has access to the parameters in itself and can invoke rules in frames TRAFFIC, DESIGN, OPERATING, and MODIFICATION.

* Frame OPERATING has access to the parameters in frames TRAFFIC and OPERATING and can invoke rules in itself.

* Frame DESIGN has access to the parameters in frames TRAFFIC and DESIGN and can invoke rules in frames DESIGN and MODIFICATION.

* Frame MODIFICATION has access to the parameters in frames MODIFICATION and DESIGN, and TRAFFIC and can invoke rules in MODIFICATION.
Figure 3.11. The Frame Structure of EXACT.
To illustrate the implications of scope or inheritance for the EXACT knowledge base, suppose that the parameter CONGESTION is initial data in frame OPERATING. If this parameter, CONGESTION, is included in the premise of a rule in the frame DESIGN, PC Plus will not be able to find a value for CONGESTION when it tests the rule. A simple solution for this dilemma is to ask for essential information in the root frame, TRAFFIC; such information will be accessible to all frames in the knowledge base. That is, including the parameter CONGESTION in the root frame will make it stand as a global variable in the program.

Now we developed the knowledge base. First, we constructed the root frame TRAFFIC. The function of TRAFFIC is to introduce EXACT to the user and direct the user to either the DESIGN or the OPERATING subframes, according to the user's desire.

The frame DESIGN leads the user to a recommended design of detector systems, time settings, and controller features for a particular approach at a given intersection. At several prompts, the user must provide specific information, including speed, street type, grade, lane width, volume, and movement. EXACT examines the user's information within the frame DESIGN and gives a recommended traffic control design, which is called an initial design. The role of the subframe MODIFICATION is to modify the initial design based on an additional information provided by the user. For example the initial design was based on the most typical lane widths (i.e., eleven and twelve ft.); widths other than these widths are handled in the frame MODIFICATION. At the end of the
consultation session the frame MODIFICATION will present the modified initial design. Figure 3.11(b), next page, illustrates the general structure of EXACT.

Although the main objective of this research is to deal with design issues of traffic signal control at isolated intersections, the frame OPERATING concerns typical operational problems that may arise in such locations. A traffic engineer occasionally needs to respond quickly to some field problems, such as sudden congestion, construction-related problems, and so forth. This frame helps the user to find practical solutions to such problems.
Figure 3.11. The Architecture of EXACT.
3.3.5.1 Properties of the Root Frame TRAFFIC and other Frames

In order for a frame to perform certain functions, we have to provide specific properties to the frame-construction phase. A frame property is a structure that contains a piece of information about the frame or controls frame's characteristics. The property INITIALDATA, for example, tells PC Plus what information to prompt a client for when it first instantiates a frame. PC Plus provides the developer with a set of properties for a frame, so the developer can choose the properties that fulfill his/her needs. As mentioned previously, the objective of the TRAFFIC frame is to introduce EXACT to the client and to direct the course of the consultation through the DESIGN or OPERATING subframe. All the properties of the TRAFFIC frame by which these functions achieved are shown in Figure 3.12.

The property TRANSLATION, shown in Figure 3.12, provides the user with text to describe the purpose or content of the frame. Within this text there are a few formatting commands, such as :LINE and :ATTR. Such formatting commands make the text more attractive and easier for the user to read. The :LINE command, followed by a number, advances that number of lines. The :ATTR command changes the display attributes of the text that follows this command. Display attributes, e.g., color and monitor's intensity, remain unchanged until another attribute is set. The PROMTOVER property controls an explanatory screen that can appear at the beginning of a frame instantiation. At the beginning of a consultation this property will display the screen shown in Figure 3.13, which presents information about EXACT to the user.
Frame :: TRAFFIC

IDENTIFIER :: "TRAFFIC-"  
TRANSLATION :: (the selection of detector type and location) 
GOALS :: (CONCLUSION) 
PROMPTEVER :: ((LINE :ATTR (MAGENTA HIGH)) " Expert System  
Actuated Control for Traffic at Isolated" :LINE " 
Signalized Intersections" :LINE 2 " 
(EXACT)" :LINE 2 :ATTR (CYAN HIGH) 
HIGH ) "This Expert System helps you select a detector type, location, and timing" :LINE "parameters of a  
traffic-actuated controller unit at isolated intersections." :LINE 2 "This Expert System for Isolated 
Signalized Intersections (ESIS) is based on" :LINE "  

engineering expertise obtained from experts in Columbus, Ohio." :LINE :ATTR (WHITE HIGH ) " 

" :LINE " 
  :ATTR (RED BLINK) "|-------|" :ATTR (GREEN HIGH BLINK ) "|-------|" :ATTR (GREEN HIGH BLINK ) "|---RED-||" :ATTR (GREEN HIGH BLINK) "  
  :ATTR (RED BLINK) "|---RED-||" :ATTR (GREEN HIGH BLINK) " 
  :ATTR (YELLOW HIGH BLINK) "|---YELLOW-||" :ATTR (GREEN HIGH BLINK ) "|-------|" :LINE " 
  :ATTR (RED BLINK) "|-------|" :ATTR (GREEN HIGH BLINK) " 
  :ATTR (YELLOW HIGH BLINK) "|-------|" :ATTR (GREEN HIGH BLINK) "|-------|" :LINE " 
  :ATTR (RED BLINK) "|-------|" :ATTR (WHITE HIGH) " 
  :ATTR (YELLOW HIGH BLINK) "|-------|" :ATTR (WHITE HIGH) " 
  :ATTR (GREEN HIGH BLINK) "|-------|" :LINE :ATTR (WHITE HIGH) " 

DISPLAYRESULTS :: YES 
PARMGROUP :: TRAFFIC-PARMS 
RULEGROUPS :: (TRAFFIC-RULES) 
OFFSPRING :: (DESIGN MODIFICATION OPERATING) 
TRAFFIC-PARMS :: (CONCLUSION DEMOGRAPHY GEOMETRY MACHINE NUSUAL OPERATE 
OPERATION PROBLEM RESULT ROAD SAFE TRAFFIC1 TYPE TYPE3 
VOLUME ) 
TRAFFIC-RULES :: (RULE006 RULE145)

Figure 3.12. The Properties of the Root Frame.
Current objective:

** End - press ENTER to continue.

Figure 3.13. Information to the User Provided by TRANSLATION property.
The DISPLAYRESULTS property must have a YES or a NO value. This property is responsible for controlling the display of conclusions during a consultation. The value YES displays such conclusions. Sometimes, however, the developer does not intend to display goals for a specific frame; this can be achieved by the value NO. However, if the value YES was chosen and a goal parameter has no value, a message appears saying, "unable to make any conclusions." Another value the DISPLAYRESULTS property takes is IFKNOWN, which reports the values given to the parameters in the list but it does not display the message "unable to make any conclusions" for the goal parameters that appear after the word IFKNOWN in the list and have not received a value.

The PARMGROUP and RULEGROUPS properties identify the parameter and rule groups associated with a frame, respectively. The frame properties, TRAFFIC-PARMS and TRAFFIC-RULES, include all the parameters and rule numbers that belong to the frame. Figure 3.14 displays the list of parameters used in the frame TRAFFIC, including DEMOGRAPHY, GEOMETRY, MACHINE, and CONCLUSION. The OFFSPRING property, in Figure 3.12, indicates the frames connected to the frame TRAFFIC.

The CONSIDERFRAME function directs the client to the desired subframe, DESIGN or OPERATING. This function must be included in the THEN statement of a rule that will activate in the parent frame. When PC Plus fires a rule with this function, the subframe following this function is instantiated. Figure 3.15 presents the two rules in the parent frame TRAFFIC responsible for instantiating the subframes DESIGN and OPERATION. Notice the CONSIDERFRAME function in both rules.
<table>
<thead>
<tr>
<th>Parmgroup: TRAFFIC-PARMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONCLUSION</td>
</tr>
<tr>
<td>DEMOGRAPHY</td>
</tr>
<tr>
<td>GEOMETRY</td>
</tr>
<tr>
<td>MACHINE</td>
</tr>
<tr>
<td>NUSUAL</td>
</tr>
<tr>
<td>OPERATE</td>
</tr>
<tr>
<td>OPERATION</td>
</tr>
<tr>
<td>PROBLEM</td>
</tr>
<tr>
<td>RESULT</td>
</tr>
<tr>
<td>ROAD</td>
</tr>
<tr>
<td>SAFE</td>
</tr>
<tr>
<td>TRAFFIC1</td>
</tr>
<tr>
<td>TYPE</td>
</tr>
<tr>
<td>TYPE3</td>
</tr>
<tr>
<td>VOLUME</td>
</tr>
</tbody>
</table>

The last comment

Figure 3.14. The List of Parameters of the Root Frame.
If the problem to be studied is DESIGN,

Then 1) instantiate the frame four approach subframe if appropriate, and
2) instantiate the frame the unusual conditions if appropriate, and
3) it is definite (100%) that The last comment is

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

If the problem to be studied is OPERATION,

Then 1) instantiate the frame This frame concerns with operational problems that the traffic professional may face. if appropriate, and
2) it is definite (100%) that The last comment is

This concludes the operation session. The next menu will have various options.

Figure 3.15. The Rules for Instantiation in the Root Frame.
Frame::DESIGN

IDENTIFIER::DESIGN-
TRANSLATION::(four approach subframe)
PARENTS::(TRAFFIC)
GOALS::(EQUIP PASSAGE MINGREEN TIME3 TIME2 TIME1 TYPE2)
INITIALDATA::(DEMOGRAPHY STREET SPEED GRADE)
PROMPTEVER::(LINE "":ATTR (RED) "THE DESIGN OF EACH APPROACH":LINE 3 :ATTR (YELLOW HIGH) "EXACT is developed to design each approach individually. After prompting you":LINE "for certain information regarding an approach, EXACT will produce a":LINE "conclusion for that approach. That is, you need to enter data for each":LINE "approach of your intersection separately."":ATTR (WHITE HIGH) :ATTR (YELLOW HIGH) "This stage is called the INITIAL":LINE "DESIGN stage. The system will allow you to modify this initial design if you":LINE "need to do so." )
PROMPT2ND::(would you like to design the next approach?)
DISPLAYRESULTS::YES
PARMGROUP::DESIGN-PARMS
RULEGROUPS::(DESIGN-RULES)
DESIGN-PARMS::(DELAY1 DILEMA EQUIP GRADE HEAVY LEFT LEFTTURN LGREEN MINGREEN MOVE1 PASSAGE SPEED SPEED1 STOPLINE STREET TIME TIME1 TIME2 TIME3 TIMING TYPE2 TYPE5 VOLUME1 VOLUME2 WIDTH WIDTH1 WIDTH2 WIDTH3 WIDTH4 WIDTH5 )
DESIGN-RULES::(RULE009 RULE010 RULE012 RULE014 RULE022 RULE024 RULE030 RULE031 RULE041 RULE042 RULE043 RULE044 RULE045 RULE046 RULE047 RULE048 RULE049 RULE050 RULE052 RULE067 RULE068 RULE069 RULE070 RULE071 RULE072 RULE073 RULE074 RULE075 RULE076 RULE077 RULE078 RULE079 RULE080 RULE081 RULE082 RULE083 RULE084 RULE085 RULE086 RULE087 RULE088 RULE089 RULE090 RULE091 RULE092 RULE093 RULE095 RULE097 RULE098 RULE099 RULE100 RULE101 RULE102 RULE103 RULE104 RULE111 RULE112 RULE113 RULE114 RULE115 RULE116 RULE117 RULE118 RULE119 RULE120 RULE121 RULE122 RULE123 RULE124 RULE125 RULE126 RULE127 RULE130 RULE131 RULE132 RULE133 RULE134 RULE135 RULE136 RULE137 RULE138 RULE139 RULE140 RULE141 RULE142 RULE143 RULE144 RULE145 RULE146 RULE147 RULE148 RULE149 RULE150 RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE157 RULE158 RULE159 RULE160 RULE161 RULE162 RULE163 RULE164 RULE165 RULE166 RULE167 RULE168 RULE169 RULE170 RULE171 RULE172 RULE173 RULE174 RULE175 RULE176 RULE177 RULE178 RULE179 RULE180 RULE181 RULE182 RULE183 RULE184 RULE185 RULE186 RULE187 RULE188 RULE189 RULE190 RULE191 RULE192 RULE193 RULE194 RULE195 RULE196 RULE197 RULE198 RULE199 RULE200 RULE201 RULE202 RULE203 RULE204 RULE205 )

Figure 3.16. The Properties of the DESIGN Subframe.
Frame :: MODIFICATION

IDENTIFIER :: MODIFICATION-
TRANSLATION :: (the unusual conditions)
PARENTS :: (TRAFFIC)
GOALS :: (DIME CONDITION DRIVE TYPE3)
PROMPTEVER :: (:LINE "" :ATTR (BLUE HIGH) "" :LINE 3 :ATTR (WHITE HIGH) "" :ATTR (MAGENTA HIGH) "Once the design stage is complete, EXACT will allow you to make modifications on your design. These modifications include:" :LINE 2 " - Stopline Location" :LINE " - Lane Width" :LINE " - Pavement Condition" :LINE " - Driveway Presence" :LINE 3 :ATTR (YELLOW HIGH) "***** GOOD LUCK WITH YOUR SESSION *****")
PROMPT2ND :: (:LINE "Would you like to go over the modification stage again?" )
DISPLAYRESULTS :: YES
PARMGROUP :: MODIFICATION-PARMS
RULEGROUPS :: (MODIFICATION-RULES)
MODIFICATION-PARMS :: (CONDITION CONSTRUCTION CURB DIME DRIVE DRIVEWAY INSTALLATION LANE LANE1 MIME PAVECOND PAVEMENT STOPLIN)
MODIFICATION-RULES :: (RULE007 RULE053 RULE054 RULE055 RULE056 RULE057 RULE058 RULE059 RULE060 RULE061 RULE062 RULE063 RULE065 RULE066 RULE110 RULE185 RULE186 RULE189 RULE191 RULE192 RULE193 RULE194 RULE206 )

Figure 3.17. The Properties of the MODIFICATION Subframe.
Frame :: OPERATING

IDENTIFIER :: "OPERATING-"
TRANSLATION :: (This frame concerns with operational problems that the traffic professional may face.)
PARENTS :: (TRAFFIC)
GOALS :: (RESULT3)
DISPLAYRESULTS :: YES
PARMGROUP :: OPERATING-PARMS
RULEGROUPS :: (OPERATING-RULES)
OPERATING-PARMS :: (RESULT3)
OPERATING-RULES :: (RULE169 RULE170 RULE171 RULE172 RULE173 RULE176 RULE177 RULE178 RULE179 RULE183 RULE184 )

Figure 3.18. The Properties of the OPERATING Subframe.
The subframes in EXACT have almost the same properties as the root frame, as shown in Figures 3.16, 3.17, and 3.18. The PROMPT2ND property is added to the frame DESIGN and MODIFICATION to enable the EXACT user to decide to reinstantiate a subframe. During a consultation with EXACT and at the end of frames DESIGN and MODIFICATION, EXACT asks the user whether to reinstantiate the frame. If the user responds YES, EXACT enables him/her to go over that frame again. The user can go over a frame as many times as desired, like a loop. For example, in the frame DESIGN the user can design unlimited number of approaches. This reinstatiation process is carried out by the PROMPT2ND property.

3.3.5.2 EXACT's Parameters

A parameter is a structure that identifies or contains a piece of information that PC Plus uses to arrive at a conclusion. As indicated previously, any ARL rule in the knowledge base must have a set of parameters with their values to be workable. As discussed earlier in the inheritance concept of PC Plus, parameters defined in the root frame can be accessed by other frames.

When a parameter is created, a set of properties should be given to it. These properties let PC Plus use that parameter during a consultation to reach a correct conclusion. A parameter should have at least three properties: a TRANSLATION, a TYPE, and a PROMPT. However, the only required property is the TYPE, which determines how PC Plus traces a parameter and how the client is prompted. Optional properties can be added to a parameter for certain purposes.
TRANSLATION describes the parameter. PC Plus uses this description as a reference to the parameter (in translating rules into English and in responding to WHY query during a consultation. WHY is a consultation command that provides an explanation of why EXACT prompts the client for specific information). The parameter GRADE, shown in Figure 3.19 has the TRANSLATION property, which states the grade of this approach.
Parameter: GRADE

<table>
<thead>
<tr>
<th>Translation</th>
<th>the grade of this approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prompt</td>
<td>&quot;Select the grade of this approach (Press F1 For Graphic Help):&quot;</td>
</tr>
<tr>
<td>Expect</td>
<td>&lt;=5% LEVEL &gt;5% UP &gt;5% D_DOWN</td>
</tr>
<tr>
<td>Type</td>
<td>SINGLEVALUED</td>
</tr>
</tbody>
</table>

Text that describes the parameter.

Figure 3.19. The Properties of the Parameter GRADE.
TYPE tells PC Plus what type of value a parameter can have. This property affects how PC Plus traces the parameter and how it constructs a prompt screen. PC Plus provides several values for TYPE, including MULTIVALUED, SINGLEVALUED, and YES/NO. TYPE determines how PC Plus prompts the client for a parameter value during a consultation. The TYPE in the GRADE parameter is SINGLEVALUED, which means that this property is associated with the EXPECT property. PC Plus prompts the client for the parameter value. The prompt in this case includes two choices, in the EXPECT property. These choices are \( \leq 5\% \) or \( > 5\% \). The client must select one of these choices. In the case of YES/NO value, there is no EXPECT property for the parameter. This is shown in Figure 3.20 for the CONSTRUCTION parameter in the MODIFICATION frame. PC Plus lists YES and NO below the prompt for the user to select. The USES-BY property identifies the rules whereby a parameter is used. The GRADE parameter, for example, is used in Rules 12, 14, 22, 24, 30, and 31. This identification is helpful when a parameter needs to be modified. In the next chapter, a full consultation session will be presented to demonstrate the roles of such parameters and properties.

The root frame parameters are listed in Figure 3.14. These parameters can be used in all the frames. For example, the parameter VOLUME1 is used in the DESIGN frame and could be used in other frames too. Looking at the properties of this parameter, VOLUME1, in Figure 3.21, we notice that the TYPE is singlevalued and that EXPECT refers to an expected response that is a positive number (POSITIVE-NUMBER). This is because VOLUME1 should be a numerical value. In this situation PC Plus requires another property called RANGE.
With RANGE the knowledge engineer must define the minimum and the maximum positive values that the client must select. If the client selects a number out of this range, PC Plus will prompt an error message.

<table>
<thead>
<tr>
<th>Parameter: CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSLATION :: Construction at the intersection</td>
</tr>
<tr>
<td>PROMPT :: &quot;Is there any construction on any approach(s) at the intersection?&quot;</td>
</tr>
<tr>
<td>TYPE :: YES/NO</td>
</tr>
</tbody>
</table>

Text that describes the parameter.

---

Figure 3.20. The Properties of the Parameter CONSTRUCTION.
### Parameter: VOLUME1

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Translation</td>
<td>The volume on this approach</td>
</tr>
<tr>
<td>Prompt</td>
<td>LINE &quot;What is the 15-minute peak-hour volume for the through movement?&quot;</td>
</tr>
<tr>
<td>Help</td>
<td>LINE &quot;If you have the peak-hour volume you need to&quot;</td>
</tr>
<tr>
<td></td>
<td>: LINE &quot;divide it by 4 to obtain the 15-minute peak?&quot;</td>
</tr>
<tr>
<td></td>
<td>: LINE 2 &quot;For more than one lane for the same movement,&quot;</td>
</tr>
<tr>
<td></td>
<td>: LINE &quot;the volume must be of the critical lane.&quot;</td>
</tr>
<tr>
<td></td>
<td>: LINE 2 &quot;Our expert uses his own formula to obtain...&quot;</td>
</tr>
<tr>
<td>Expect</td>
<td>POSITIVE-NUMBER</td>
</tr>
<tr>
<td>Type</td>
<td>SINGLEVALED</td>
</tr>
<tr>
<td>Range</td>
<td>10 2000</td>
</tr>
</tbody>
</table>

Text that describes the parameter.

---

Figure 3.21. The Properties of the Parameter VOLUME1.
A HELP property can be added to a parameter. This property specifies text that explains the prompt that appears to the client during a consultation. In EXACT this property is used frequently. The HELP property can increase the accuracy of the expert system's results by clarifying the prompts so that a client makes the suitable response. STREET parameter in DESIGN frame, for instance, has the HELP property. This property includes a text to help the client decide the type of street, whether major or minor. When a client presses the F1 key at the prompt screen, the text in the HELP property appears. Figure 3.22 shows the help screen for STREET after the client has pressed F1 during a consultation.

Another example of parameters is the STOPLIN parameter in the MODIFICATION frame. The properties of this parameter are illustrated in Figure 3.23. At the prompt screen, during a consultation, the client is asked about the distance between the stopline and the curbline, and a list of selections is shown below the prompt. Notice the GHELP property in the STOPLIN properties. This property displays a picture when the client presses the F1 key for help in responding to the prompt. The graph enhances the understandability of the prompt by translating the prompt graphically. To show a picture with a prompt, the GHELP property must be added to the parameter. When GHELP is selected from the list of parameter properties during the development stage of EXACT, PC Plus prompts the knowledge engineer for the name of the graphics file that contains the desired picture. This file must have the extension .GRI for IBM machines. The GHELP may include more than one picture. However, each picture must be in an external graphics file. With STOPLIN there are two pictures in two graphics files: CURB.GRI and STOPLINE.GRI. The graphics software used to build graphs in
this research is called PAINTBRUSH and will be introduced in the section titled "Interacting with an External Graphics Program." Figures 3.24, 3.25, and 3.26 present the parameters of DESIGN, MODIFICATION,
### Parameter: STOPLIN

<table>
<thead>
<tr>
<th><strong>TRANSLATION</strong></th>
<th>the location of stopline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PROMPT</strong></td>
<td>:LINE &quot;What is the distance between the stopline and the curb line or edge of&quot; :LINE &quot;pavement?&quot;</td>
</tr>
<tr>
<td><strong>EXPECT</strong></td>
<td>&lt;=15 16-20 21-25 26-30 31-35 36-40 41-45 &gt;45</td>
</tr>
<tr>
<td><strong>TYPE</strong></td>
<td>SINGLEVALUED</td>
</tr>
</tbody>
</table>

Text that describes the parameter.

Figure 3.23. The Properties of the Parameter STOPLIN.
**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

<table>
<thead>
<tr>
<th>Parmgroup: DESIGN-PARMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DELAY1 TIMING</td>
</tr>
<tr>
<td>DILEMA TYPE2</td>
</tr>
<tr>
<td>EQUIP TYPE5</td>
</tr>
<tr>
<td>GRADE VOLUME1</td>
</tr>
<tr>
<td>HEAVY VOLUME2</td>
</tr>
<tr>
<td>LEFT WIDTH</td>
</tr>
<tr>
<td>LEFTURN WIDTH1</td>
</tr>
<tr>
<td>LGREEN WIDTH2</td>
</tr>
<tr>
<td>MINGREEN WIDTH3</td>
</tr>
<tr>
<td>MOVE1 WIDTH4</td>
</tr>
<tr>
<td>PASSAGE WIDTH5</td>
</tr>
<tr>
<td>SPEED</td>
</tr>
<tr>
<td>SPEED1</td>
</tr>
<tr>
<td>STOPLINE</td>
</tr>
<tr>
<td>STREET</td>
</tr>
<tr>
<td>TIME</td>
</tr>
<tr>
<td>TIME1</td>
</tr>
<tr>
<td>TIME2</td>
</tr>
<tr>
<td>TIME3</td>
</tr>
</tbody>
</table>

The Detector Delay Timing

Figure 3.24. The Parameters of the Subframe DESIGN.
The modification for pavement conditions

<table>
<thead>
<tr>
<th>Parmgroup: MODIFICATION-PARMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONDITION</td>
</tr>
<tr>
<td>CONSTRUCTION</td>
</tr>
<tr>
<td>CURB</td>
</tr>
<tr>
<td>DIME</td>
</tr>
<tr>
<td>DRIVE</td>
</tr>
<tr>
<td>DRIVEWAY</td>
</tr>
<tr>
<td>INSTALLATION</td>
</tr>
<tr>
<td>LANE</td>
</tr>
<tr>
<td>LANE1</td>
</tr>
<tr>
<td>MIME</td>
</tr>
<tr>
<td>PAVECOND</td>
</tr>
<tr>
<td>PAVEMENT</td>
</tr>
<tr>
<td>STOPLIN</td>
</tr>
</tbody>
</table>

Figure 3.25. The Parameters of the Subframe MODIFICATION.
Figure 3.26. The Parameters of the Subframe OPERATING.
and OPERATING, respectively. A detailed list with properties for these parameters is included in the Appendix A.

3.3.5.3 Production Rules

Having structured the frames and their parameters along with the necessary properties, the knowledge engineer begins the task of building the rules. Simply, PC Plus rules are IF-THEN statements that express the relationships among parameters. PC Plus rules should be written in Lisp language or Abbreviated Rule Language (ARL).

The IF-THEN form means that if certain conditions are met, then a piece of knowledge is true or has a particular value. Four terms have meaning in relation to PC Plus rules: try, pass, fail, and fire. PC Plus tries a rule by examining first the conditions stated in its IF statement. Figure 3.27 shows an example of such conditions, including PROBLEM, SPEED, MOVE1, LEFT, and WIDTH1. (Notice these conditions are parameters in EXACT and that their definitions are listed in the Appendix A). When these conditions are met, then the IF statement is true, and it passes. When the conditions are not met, the IF statement is false, and it fails. When a rule's IF statement passes, PC Plus fires the rule, or carries out the action(s) listed in its THEN statement.

In the earlier stages of knowledge representation the knowledge engineer built decision frameworks including the main aspects of the problems. That is, these frameworks depicted the relationships among the variables (parameters) our expert used in his decision-making process, and ended up with specific goals, as discussed previously in the knowledge-representation phase. Such frameworks were built
RULE046

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LAT or LATR, Major, perm & prot/perm., and <=5%.)

IF :: (PROBLEM = DESIGN AND STREET = MAJOR AND SPEED = <=35 AND (MOVE1 = LAT OR MOVE1 = LATR) AND (LEFTURN = PERMITTED OR LEFTURN = PROTECTED/PERMITTED) AND LEFT = <=5% AND (WIDTH1 = 11 OR WIDTH1 = 12) AND (WIDTH2 = 11 OR WIDTH2 = 12))

THEN :: (TIME = ((VOLUME1 / 15) * 2.5) AND TIME3 = (TIME + 20) AND TIME2 = (TIME3 + 20) AND EQUIP = (TEXTVAL :ATTR (QUOTE (MAGENTA)) "The recommended detector type for this approach is a PROBE detector for the through-movement lane." :LINE 2 :ATTR (QUOTE (CYAN)) "CONFIGURATION: TWO PROBES are needed for this approach and should be located 110 ft. behind the stopline. Left-turning traffic is very light; therefore, it can be handled through gaps in the opposing traffic or in the yellow interval. Hence, no detector is needed." :LINE 2 :ATTR (QUOTE (YELLOW)) "RECALL: ON" :LINE 2 :ATTR (QUOTE (RED)) "MEMORY: ON")

Figure 3.27. The ARL Form of a Rule.
according to rules inferred from the expert during the knowledge-acquisition stage. Now these well-organized frameworks need to be translated to IF-THEN rules that can be translated later on to ARL rules. Figure 3.28 presents the process of developing ARL rules in this research (Appendix B lists all EXACT' Rules in English form.)

Let us present an example of building ARL rules. We take a branch in one of the frameworks depicted earlier in Figure 3.9. This branch starts with the parameter PROBLEM and goes through several parameters, such as STREET, SPEED, MOVEMENT, and LEFTURN down to a goal parameter. First an IF-THEN rule in an English transcription is built out of this branch:

If the problem is design and the street is major and the speed is less than or equal to 35 mph and the movement in this approach is left-turning and through, and if the left-turning movement is permitted or protected/permitted and the percentage of the left-turning volume is less than or equal to 5%, and if the width of the first lane from the curb is 11 or 12 ft. and the width of the second lane from the curb is 11 or 12 ft, then the detector type is a probe and its configuration is given.

This rule has eight conditions in its IF statement. These conditions represent the parameters used in this rule. Each parameter must have a specific value in order for the rule to pass. The value of STREET parameter, for instance, is MAJOR. Now this rule is translated into ARL form, which shows all the parameters with their values used on both sides of this rule. Figure 3.27 shows this ARL form. Notice that we have a TIME parameter in the THEN statement of the ARL rule. This goal parameter has a computation formula in its value, which enables EXACT to calculate green time based on the VOLUME entered by the user during a consultation. The calculating capability is one feature of PC Plus.
Figure 3.28. The Process of Developing the ARL Rules in EXACT.
EXACT can translate the ARL rule into an English sentence. This feature helps the developer to understand the coded rules for any future manipulating. The property TRANSLATION of a parameter, discussed before, is responsible for defining each parameter in the rule in its English form. Figure 3.29 illustrates the PC Plus English form for the previous rule.

3.3.5.4 Rules Connecting Frames

Rules can form a connecting ring among frames. EXACT has three subframes DESIGN, MODIFICATION, and OPERATING besides its root frame, TRAFFIC. Rules 006 and 145 (presented earlier in Figure 3.15) in the knowledge base are responsible for such a connection. The CONSIDERFRAME function (explained earlier in the instantiation definition) is used inside both rules to perform the connection. Once rule 006 is fired (shown in Figure 3.15), the CONSIDERFRAME function will instantiate both the DESIGN and the MODIFICATION frames. The instantiating is performed in the order given in the rule. Rule 145, shown in Figure 3.15, is responsible for the instantiation of the frame OPERATING.

3.3.5.5 Interacting with an External Graphics Program

PC Plus can integrate graphs into an EXACT knowledge base. The name of the utility is SNAPSHOT. With SNAPSHOT, if the computer has the required graphics capabilities, it is possible to display pictures during a consultation.

During a consultation with EXACT the user can display a picture at several places in the knowledge base. First, a picture can be displayed at a certain prompt when F1 is pressed for an explanation. EXACT can show pictures in two different
RULE046

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LAT or LATR, Major, perm & prot/perm., and <=5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LAT, or
   2) the movement on this approach is LATR, and
5) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach ? is <=5%, and
7) 1) The width of the first lane is 11, or
    2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
    2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector for the through-movement lane.

CONFIGURATION: TWO PROBES are needed for this approach and should be located 110 ft. behind the stopline. Left-turning traffic is very light; therefore, it can be handled through gaps in the opposing traffic or in the yellow interval. Hence, no detector is needed.

RECALL: ON
MEMORY: ON.

Figure 3.29. The English Form of a Rule.
locations during a consultation. First, a picture can be shown at a prompt to give
some information to the client. For example, at the MOVE1 (A parameter defines
the type of mvoement) prompt a long list with coded choices(shown earlier in
Figure 3.3) appears to the client. The client must make a selection from this
ambiguous list. Without graphic help, the user will not be able to understand such
codes. By pressing F1, the user can get a detailed picture for these codes, as shown
in Figure 3.3.

The second location where a picture can be shown is at the conclusions
screen when EXACT carries out the action of the THEN statement of a rule. With
the passage time conclusion, a graph shows the relationship between passage time,
location of the intersection, and grade, as illustrated in Figure 3.5. This plot gives
the user an idea about the recommended ranges of passage time for different grade
levels and intersection locations.

For a picture shown with a prompt during a consultation, GHELP property
must be defined in the prompt-parameters properties. The GHELP property,
explained earlier in the parameters section, permits the user to get a picture by
pressing F1. Figure 3.30, for instance, shows the properties of the parameter
MOVE1, and the GHELP property is listed with the name of the graphics file of
the picture. At the MOVE1 prompt, once the user presses F1, the picture will
appear.

For a picture shown with a conclusion, a different technique is used to make
it appear. This technique requires the graphics file name to be included in the
THEN statement of a rule. A special function called =G must be included too. The
rule presented in Figure 3.31 shows how =G function within the THEN part.
**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

<table>
<thead>
<tr>
<th>Parameter: MOVE1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRANSLATION</strong>: the movement on this approach</td>
</tr>
<tr>
<td><strong>PROMPT</strong>: &quot;What is the type of movement on this approach? (Press F1 for HELP)&quot;</td>
</tr>
<tr>
<td><strong>EXPECT</strong>: T TL TR LTR TT LTT LTTT LTTTR LTTTTR LATTTR LATTTR LATT TTTR LLTR LTTTTR LATTTR LATTTR LATT</td>
</tr>
<tr>
<td><strong>GHELP</strong>: &quot;move1&quot;</td>
</tr>
<tr>
<td><strong>TYPE</strong>: SINGLEVALUED</td>
</tr>
</tbody>
</table>

Text that describes the parameter.

---

**Figure 3.30.** The Properties of the Parameter MOVE1.
RULE012

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Passage Time)
IF :: (SPEED <=35 AND DEMOGRAPHY = TYPE_1 AND GRADE <=5%_LEVEL)
THEN :: (PASSAGE =G "passage" AND PASSAGE = (TEXTVAL :ATTR (QUOTE (GREEN)))) "2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation."

Figure 3.31. A Rule with a =G Function in its Action Part.
We have discussed so far how to implement graphics in EXACT but what exactly in EXACT makes it possible to display such pictures? Before a picture can be displayed in EXACT, two major steps must be taken:

1. Create the picture itself.

2. Implement PC Plus compression and expansion tools.

To create a picture, a third-party graphics is needed. In PAINTBRUSH, the graphics program used in this research to create pictures, a mouse creates any kind of drawings. This graphics program provides a free drawing area in which a picture can be created. The picture must be saved in a specific graphics file with a certain extension. The program exists in a different directory from PC Plus; the SNAPSHOT utility must be copied in this directory to integrate both programs. For example, the graphic file "move1," shown in Figure 3.30, was saved as "move1.gri" and copied from PAINTBRUSH directory to PC Plus directory.

SNAPSHOT, mentioned earlier, has two main tools: the Compression tool and the Expansion tool. These tools are responsible for producing a picture that will appear to the client during a consultation with the EXACT knowledge base. The compression tool compresses the picture in a file before copying it in the EXACT directory. During a consultation when a graphics file is called, the Expansion tool expands the picture that has been captured in the graphics file to appear in the terminal screen.

3.3.6 Testing and Evaluation of EXACT

When we started developing EXACT, we continually tested it by running consultations, and we repeated these consultations whenever we added rules or made modifications. This process helped us to uncover problems in the system
regarding its conclusions, the content of its rules, the interaction of the rules, and the improper usage of PC Plus properties.

Another concern of testing was that the client be able to communicate clearly with the system during a consultation. Therefore, we asked our expert and other experts to report any unclear or ambiguous prompts or conclusions; and then we clarified these through the PRINT, TEXTVAL (Both properties display parameter values, numbers, or text strings in certain format when EXACT carries out the action of a THEN statement), HELP, and GHELP properties.

Through our testing, we intended to achieve three goals:
1. Technically, the system will work as expected, and its inference engine will produce plausible solutions.
2. The system will reflect the expert's actual problem-solving reasoning process.
3. The system will have been tested by other experts to find essential points of disagreement between their solutions and those given by EXACT.

Figure 3.32 illustrates the stages of the testing process for EXACT.

### 3.3.6.1 Technical Ability of the System

Examining the technical ability of EXACT is the first step in the testing phase. The goal of this step is to test the logical flow of the inference mechanism in working toward a conclusion. Fortunately, the PC Plus shell provides special features, through TRACE commands, to help the knowledge engineer to do this testing. The TRACE ON command can generate a written record of the logical flow of a consultation as it moves toward a conclusion. When the knowledge
engineer presses the F2 key, a commands menu, including the TRACE ON command, appears. After the knowledge
engineer selects this command, EXACT asks the engineer to indicate a destination for the Trace output. Figure 3.33 shows both the commands menu and these choices. If the knowledge engineer wants to trace parts of a long consultation, the TRACE OFF command can be used.

EXACT provides the following choices:

* Screen -- Print the Trace output on the screen during the consultation.
* Printer -- Send the Trace output to the printer.
* New file name -- Send the trace output to a file that the knowledge engineer specifies in response to the next prompt.

Now an example for tracing the logical flow of EXACT in the MODIFICATION subframe is presented in order to show how to test the logic of the system. In this example several screens, taken from the knowledge engineer's consultation with the EXACT knowledge base, show the kind of information that appears in the TRACE ON output. The first screen, in Figure 3.34, shows that EXACT intends to trace the goal parameters: DIME, CONDITION, DRIVE, AND TYPE3. It will begin by tracing the rules that deduce the goal parameter DIME (an acronym stands for the dimension of detectors with respect to lane width): RULE059 and the other listed rules. Then EXACT will compare the premise of each rule with the inputs that the knowledge engineer provides. In this case the first tracing parameter tested is LANE1.
Figure 3.33. The Commands Menu and the Outputs' Destination Choices.
Frame MODIFICATION-2 created under TRAFFIC-1
Trace the following goals: DIME CONDITION DRIVE TYPE3
Tracing parameter: MODIFICATION-2 DIME
Try the rules that deduce MODIFICATION-2 DIME: RULE189 RULE053 RULE054 RULE055 RULE056 RULE058 RULE059 RULE057
Testing rule premise: MODIFICATION-2 RULE189
Tracing parameter: MODIFICATION-2 LANE1

** End - press ENTER to continue.

Figure 3.34. Tracing the Goal Parameter Dime.
The next Trace output, presented in Figure 3.35, shows that EXACT has set the value of LANE1 as YES and has begun testing the premises of other rules. It shows also that some rules' premises fail but that rule 54 for the LANE parameter passes the test.

--- USER ENTRY ---: MODIFICATION-2 LANE1 = (YES 100)
Setting parameter : MODIFICATION-2 LANE1 = YES cf 100
End tracing parameter: MODIFICATION-2 LANE1
Tracing parameter : MODIFICATION-2 LANE
--- USER ENTRY ---: MODIFICATION-2 LANE = (13 100)
Setting parameter : MODIFICATION-2 LANE = 13 cf 100
End tracing parameter: MODIFICATION-2 LANE
Rule premise fails : MODIFICATION-2 RULE189
Testing rule premise : MODIFICATION-2 RULE053
Rule premise fails : MODIFICATION-2 RULE054
Testing rule premise : MODIFICATION-2 RULE054
Apply action : MODIFICATION-2 DIME = :ATTR (CYAN) "For the LOOP design you will need a 7' x 25' loop to avoid interference with adjacent traffic. This design will leave 3' between the edge of the loop and the lane line. For the PROBE design two probes are adequate." cf 100
Completed action : MODIFICATION-2 RULE054

** End - press ENTER to continue.

Figure 3.35. Rule 54 Passes.
Once the premise of rule 54 passes, EXACT applies the rule action (the left-hand side of the rule), setting the value of the goal parameter DIME to the text shown in Figure 3.36. The last line in this figure shows that EXACT has stopped tracing DIME.

--- USER ENTRY ---
Setting parameter : MODIFICATION-2 LANE = (13 100)
End tracing parameter: MODIFICATION-2 LANE
Rule premise fails : MODIFICATION-2 RULE054
Testing rule premise : MODIFICATION-2 RULE054
Apply action : MODIFICATION-2 RULE054 TALLY 100
Setting parameter : MODIFICATION-2 DIME = :ATTR (CYAN) "For the LOOP design you will need a 7' x 25' loop to avoid interference with adjacent traffic. This design will leave 3' between the edge of the loop and the lane line. For the PROBE design two probes are adequate." of 100
Completed action : MODIFICATION-2 RULE054

Figure 3.36. EXACT Completed Tracing DIME.
The same process of tracing continues with the other goal parameters: 
CONDITION, DRIVE, and TYPE3.

Besides TRACE commands, the PC Plus shell provides properties, such as INITIALDATA and GOALS to help EXACT process the rules more efficiently. These properties influence the order in which EXACT searches for parameters.

3.3.6.2 The System's Conformity to the Expert's Reasoning Process

The expert has been involved in testing EXACT from the early stages of its development. The knowledge engineer has constantly been asking the expert to test the system with case examples and has been obtaining the expert's opinion about the way the system runs and the solutions it provides. The expert and the knowledge engineer have checked many rules for accuracy and completeness. The expert's input has helped the knowledge engineer to modify incorrect or incomplete rules and to exclude or combine some of the rules' parameters. Through this step, the expert and the knowledge engineer have found rules that were incorrect, incomplete, or missing. Finding such problems is important because if uncorrected, these problems would obstruct the logical flow of the system. For example, imagine that the value of a parameter is used in a rule but that this value does not exist in the parameter's EXPECT property. In this case this rule will not be fired, and no conclusion can be reached with respect to the piece of information entered by the user in that rule.

To achieve the goal of agreement between our expert and EXACT, the knowledge engineer asked the expert to use EXACT to solve ten real-world cases, provided by the City of Columbus and solved by the expert in the past. Then the
knowledge engineer compared the solutions with those of EXACT. (Table 3.3 presents the names of intersections used in this test.) Encouragingly, EXACT's solutions matched those of the expert in more than 90% of the time. This high percentage of agreement occurred because the expert's knowledge was used in building the knowledge base of the system and also because the expert was involved in developing EXACT from the very beginning. The expert gave each case a percentage of agreement, and the knowledge engineer determined the overall percentage of agreement. For instance, if the expert agreed fully on EXACT's solution, he gave that solution a rating of 100 percent, but if he disagreed entirely he gave the solution a rating of zero percent. If he agreed partially, he gave the solution a rating of between zero and 100 percent, according to his best estimate. All these percentages are presented in the third column of Table 3.3. The average of those percentages is around 90% representing the overall agreement between EXACT's solutions and our expert's solutions.

Two of the ten cases will be presented below as examples. The first case was successful, so the expert agreed 100% with EXACT's solution. In the other case the expert partially agreed.

**First Case**

A two-lane approach (shared-right lane) was tested. The data describing the characteristics of this approach is given in Figure 3.37. EXACT's solution is presented in Figure 3.38. Our expert agreed on this solution one hundred percent.
Consultation record:

Consultation log: Expert System for ... :: DESIGN
the problem to be studied :: TYPE_I
The location of the given intersection :: TYPE_I
The street type either main or minor :: MAJOR
speed on this approach :: >35
the grade of this approach :: <=5%_LEVEL
the movement on this approach :: TT
The width of the first lane :: 12
the width of the second lane :: 12
The volume on this approach :: 297
The speed of the high speed approach :: 50
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2:the unusual conditions :: NO

Figure 3.37. The First Case Characteristics.
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 293 ft. behind the near probes.
The EXTENSION time for the far probes: 2.5 sec.
The Minimum Green Time Setting is as follows: 20 sec.
MAX I Green Time is as follows: 69.5
MAX II is as follows: 89.5
Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case
The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

Figure 3.38. EXACT's Solution for the First Case.
Second Case

A two-lane approach (shared left lane and shared right lane) was tested. Figures 3.39 and 3.40 present the characteristics of this approach and EXACT's solution, respectively. Unlike the previous case, the expert partially disagreed in this case. Since the street is major and has a high speed approach, the expert disagreed on the MEMORY feature of the controller unit. Therefore, this case scored 90%. Table 3.3 shows how the percentages for the two examples were distributed. (All the ten cases with the expert's evaluations are presented in Appendix E.)
Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either main or minor :: MINOR
speed on this approach :: \( \leq 35 \)
the grade of this approach :: \( \leq 5\% \) LEVEL
the movement on this approach :: LTTR
The width of the first lane :: 11
the width of the second lane :: 11
The volume on this approach :: 169
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any ... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2:the unusual conditions :: NO

Figure 3.39. The Second Case Characteristics.
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane and should be located at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 10 sec.
MAX I Green Time is as follows: 38 sec.
MAX II is as follows: 58 sec.

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Figure 3.40. EXACT's Solution for the Second Case.
Table 3.3. The intersections used in the real case examples.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Geometry</th>
<th>% of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad St. with Rose Hill Rd. (Eastbound)</td>
<td>Two-lane approach (Shared right)</td>
<td>100</td>
</tr>
<tr>
<td>Broad St. with Rose Hill Rd. (Westbound)</td>
<td>Three-lane approach (Protected left turn)</td>
<td>95</td>
</tr>
<tr>
<td>Alum Creek with Livingston Ave. (Northbound)</td>
<td>Two-lane approach (Shared-left lane and shared-right turn)</td>
<td>90</td>
</tr>
<tr>
<td>Taylor Ave. with Leonard Ave. (Northbound)</td>
<td>One-lane approach (Shared left turn)</td>
<td>95</td>
</tr>
<tr>
<td>Leonard Ave. with Champion (Westbound)</td>
<td>Two-lane approach (Protected left turn)</td>
<td>95</td>
</tr>
<tr>
<td>Alum Creek Drive with Main St. (Northbound)</td>
<td>Two-lane approach (Protected left and right turn)</td>
<td>95</td>
</tr>
<tr>
<td>Dublin Road with Fifth Ave. (Northbound)</td>
<td>Three-lane approach (Protected left turn and shared right turn)</td>
<td>85</td>
</tr>
<tr>
<td>Fifth Avenue with Dublin (Westbound)</td>
<td>Two lane approach (Shared left turn and protected right lane)</td>
<td>90</td>
</tr>
<tr>
<td>Broad St. with Cardinal Park Dr. (Eastbound)</td>
<td>Three-lane approach (protected left turn)</td>
<td>90</td>
</tr>
<tr>
<td>Fifth Ave. with Nelson Rd. (Westbound)</td>
<td>Three-lane approach (protected left turn and shared right lane)</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>92</td>
</tr>
</tbody>
</table>
3.3.6.2 Outside Experts

Involving other experts to test the system's performance was the last step of the testing stage. The two goals of this step were:

1. To find out whether the system's solutions agreed or disagreed with experts' solutions.
2. To find out whether the system adequately explains the reasons for its conclusions and all details in both the conclusions and the prompts.

Two experts from Cincinnati, Ohio, (Benjamin McKay and Martha Kelly, city traffic engineers in the Traffic Engineering Division, Department of Public Works, city of Cincinnati took time to test EXACT. Generally speaking, they agreed eighty percent of the time with the system's solutions, as shown in Table 3.4. They believe that EXACT could be beneficial to traffic practitioners who understand the basic concepts of actuated control as well as to experts in the field, who would be exposed through EXACT to different expertise.

This is how the test was conducted. First we explained the system and its objectives to the experts. Next, after a tutorial session, the experts used EXACT to design actuated control for six hypothetical cases. Then the experts compared EXACT's solutions with the solutions they would have reached without using EXACT. To our satisfaction, more than eighty percent agreement was found, as shown in Table 3.4. Again, this percentage represents the overall agreement between the EXACT's solutions and the experts' solutions. In the second case presented in Table 3.4, a one-lane high speed approach was designed. Figures 3.41
and 3.42 show the characteristics of this approach and the solution recommended by EXACT, respectively.
Consultation record:

<table>
<thead>
<tr>
<th>Consultation log: Expert System for ...</th>
<th>::</th>
</tr>
</thead>
<tbody>
<tr>
<td>The problem to be studied</td>
<td>:: DESIGN</td>
</tr>
<tr>
<td>the location of the given intersection</td>
<td>:: TYPE_I</td>
</tr>
<tr>
<td>The street type either main or minor</td>
<td>:: MAJOR</td>
</tr>
<tr>
<td>speed on this approach</td>
<td>:: &gt;35</td>
</tr>
<tr>
<td>the grade of this approach</td>
<td>:: &lt;=5%_LEVEL</td>
</tr>
<tr>
<td>the movement on this approach</td>
<td>:: T</td>
</tr>
<tr>
<td>the width of through lane (s)</td>
<td>:: 11</td>
</tr>
<tr>
<td>The volume on this approach</td>
<td>:: 99</td>
</tr>
<tr>
<td>The speed of the high speed approach</td>
<td>:: 40</td>
</tr>
<tr>
<td>2:four approach subframe</td>
<td>:: NO</td>
</tr>
<tr>
<td>Modification for lane width</td>
<td>:: NO</td>
</tr>
<tr>
<td>pavement condition : Is there any Pr...</td>
<td>:: NO</td>
</tr>
<tr>
<td>Driveway around the intersection</td>
<td>:: NO</td>
</tr>
<tr>
<td>the location of stopline</td>
<td>:: &lt;=15</td>
</tr>
<tr>
<td>2:the unusual conditions</td>
<td>:: NO</td>
</tr>
</tbody>
</table>

Figure 3.41. The Case Study Characteristics.
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach. The exact locations of probes are given next.

RECALL: ON
MEMORY: OFF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage Time setting is 2.0 seconds.

The NEAR PROBES should be located 110 ft. behind the stopline.

The FAR PROBES should be located 220 ft. behind the near probes.

The EXTENSION/time for the far probes: 2.3 sec.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 31.5

MAX II is as follows: 46.5

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case.

The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended inlaid design is based on 11 and 12' lanes.

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: Two choices you have in this case: 1) Relocate the stopline to ensure a 15' distance between the front of the loop and the curbline; this is more preferable or 2) Keep a minimum distance 5' between front of the loop and the curbline.

Figure 3.42. EXACT's Solutions for the Case Study.
The experts agreed fully on the detector type and the controller's features, and the time settings, but they disagreed partially on the controller type. Therefore, they rated their agreement as 85 percent. The experts rated their agreement on the sixth case, as only ten percent. This low percentage is due to the difference in designing practices between experts in Cincinnati and Columbus. That is, with double-left turn lanes, the experts from Cincinnati prefer to use several 6' x 6' loops (small loops) placed 20 ft. back from the stopline. However, our expert from Columbus prefers a 6' x 20' loop design to screen out false calls (such as occur with a right-turn-on-red situation or during off-peak periods, particularly in night time.) This case might be excluded because of the difference; however, even including this case, the overall percentage of agreement is still high, approximately seventy percent. Because EXACT is based on Columbus expertise, it is realistic to drop this case from the evaluation process (All the six cases are included in Appendix D.)

As expected, minor disagreements were found in some cases. These disagreements can be attributed to the following:

1. Different practices of actuated control design between Columbus and Cincinnati. For example, in Columbus our expert selected a short loop (25 ft. long) in his design because of the maintenance problems and costs. However, the experts in Cincinnati did not have the same perspective; they selected a long loop or several small loops for approach. Although such differences in practice may not have a significant impact on operational performance, our Columbus expert seems to be more sensitive to the maintenance cost and the likely traffic operational problems, such as congestion, that might result due to lane(s) closure during the maintenance period. According to our expert from Columbus, in addition to approximately $600
in labor and equipment costs, installing a new loop (6' x 20') requires at least a four-hour period to close the lane where this loop is placed. The longer the loop, the longer the time. Thus, economic and operational factors affect a traffic engineer's design. As another example, our expert in Columbus uses MAX I and MAX II to handle peak-time traffic conditions, but the Cincinnati experts prefer to set the controller on the basis of different cycle lengths during a day.

2. Unclear conclusions occasionally given by EXACT. For example, the recommendation of the stopline modification in EXACT's conclusion was not clear to the external experts.

3. Lack of some definitions for the technical terms used in EXACT. One major problem in the area of actuated control is the lack of a uniform vocabulary. Different manufacturers as well as different local transportation agencies employ different terms for the same concept in the field. "Passage time," for instance, is variously referred to as "extension interval," "unit extension," and "unit interval." If an expert is not familiar with these synonyms, he/she might be confused. To alleviate part of this problem EXACT was modified, and all terms are provided with their definitions.

Briefly, the testing stage was essential in order to refine the system and to improve its understandability. Based on the criticism we received from both our internal expert and our external experts, we have modified the system. Although the modification stage is completed, future testing could increase the system's reliability. That is, the run-time version of EXACT could be sent to traffic engineering practitioners (both experts and non-experts in traffic-actuated control) in order for them to evaluate the system. In fact, the testing of expert system is an
endless process. Nevertheless, the reactions obtained from our three experts were quite satisfactory and increase our confidence in EXACT's performance.
Table 3.4. The Agreement between EXACT and Outside Experts

<table>
<thead>
<tr>
<th>Case #</th>
<th>Description</th>
<th>Percentage of Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>One lane approach low speed approach</td>
<td>85%</td>
</tr>
<tr>
<td>2</td>
<td>One lane approach high speed approach</td>
<td>85%</td>
</tr>
<tr>
<td>3</td>
<td>Two lane approach low speed approach protected left turn</td>
<td>60%</td>
</tr>
<tr>
<td>4</td>
<td>Two lane approach low speed approach permitted left turn &lt;= 5% left-turns</td>
<td>85%</td>
</tr>
<tr>
<td>5</td>
<td>Two lane approach low speed approach permitted left turn &gt; 5% left turns</td>
<td>90%</td>
</tr>
<tr>
<td>6</td>
<td>Four lane approach Double left turns</td>
<td>10% (The percentage of agreement very low because of different design practice for the double left turns.)</td>
</tr>
</tbody>
</table>

Average Agreement (excluding Case 6) = 81%
4.1 Introduction

Before we demonstrate the use of EXACT with a case example, we shall describe how the program performs. As mentioned in the previous chapter, EXACT consists of three basic subframes besides the root frame, TRAFFIC : DESIGN, MODIFICATION, and OPERATING. When a consultation begins, EXACT starts running in the TRAFFIC frame by asking the user to select either the subframe DESIGN or the subframe OPERATING, as depicted in Figure 3.11 in the previous chapter. The DESIGN module of EXACT designs a new detection system along with time settings for one or all approaches at an intersection. On the other hand, the OPERATING module solves traffic control problems at an intersection with an already existing detection system and timing parameters. Note that EXACT was mainly constructed for designing purposes.

Suppose a user selects the DESIGN subframe at the beginning of a consultation. Accordingly, the TRAFFIC frame leads the user to the DESIGN subframe. Now several prompts appear, and the user must respond to them. EXACT requires three kinds of responses: 1) YES/NO, 2) a choice the user must make from a list, and 3) a numerical value. At the end of the DESIGN subframe, EXACT gives its design recommendation (the conclusion) for the given problem. This design, called the initial design, is based on the most typical cases of design, including a lane width of eleven or twelve feet, a standard stopline location, and
good pavement conditions. EXACT next leads the user to the MODIFICATION
subframe to modify the initial design based on the problem characteristics. For
example, if the lane width is other than eleven or twelve feet the user can modify
the initial design. At the end of the modification stage, EXACT provides a
conclusion modified according to the problem characteristics (the final conclusion).

Now suppose that instead of the DESIGN module, the user chooses the
OPERATING module. This subframe deals with the most frequent problems
associated with an existing traffic-actuated control. That is, the user is faced with
real-world operating problems and wants to respond to them quickly. For example,
if congestion is the problem, EXACT asks the user for specific information and
gives a set of practical solutions from which the user can select. The DESIGN and
OPERATING modules of EXACT are presented in Figure 4.1.

At the end of a consultation, a menu of commands will present several
choices. For instance, if the user wants to print a complete record of the
consultation session, he/she must select print command. Other commands are to
start again with a new session or to exit EXACT. These commands are explained
in the next section.

4.2 Installation Runtime Diskette

To install the runtime software, the user is expected to have a working
knowledge of DOS commands. Although the runtime version can be run from a
high-density diskette drive, it is better to run it from a hard disk drive. To consult
with EXACT, first it needs to be installed in the hard disk drive in this manner:
Figure 4.1. EXACT's Modules of Solution: (a) Design, (b) Operation.
1. Get into the hard disk prompt and create a subdirectory with the name `EXACT` (the name is optional) as follows:
   
   ```
   x > md EXACT
   ```
   
   where x is the hard-disk drive designator.

2. Place the Runtime diskette in Drive A.

3. Type the following command, and press the ENTER key:
   
   ```
   a: install x: \EXACT
   ```

### 4.3 Hardware Requirements

The minimum hardware requirements for running EXACT vary, depending upon whether the system is to be used for knowledge base development or for running the delivery version. This section describes the minimum configuration requirements needed for both the development system and the delivery system.

#### 4.3.1 Development System

The knowledge engineer can consult with EXACT through the CONSULT activity provided by PC Plus software. However, to develop EXACT or to modify it through the DEVELOP activity, the following specific hardware requirements are needed:

- One double-sided, double-density diskette drive
- A hard disk drive with at least 1.5 megabytes of available workspace
- At least 640k bytes of memory
- MS-DOS version 2.1 or above
- An IBM Personal Computer or AT compatibles
4.3.2 Delivery System

Consultation can be performed by the client through the run-time version of EXACT (the delivery system). The knowledge engineer prepares this version through the BUILD activity in a high-density diskette. The minimum system requirements for the run-time version of EXACT which will be used by clients are as follows:

- Two double-sided, double-density diskette drives
- A hard disk for large knowledge bases (those exceeding 360 k bytes)
- A minimum of 640k bytes of RAM memory
- MS-DOS version 2.1 or above
- An IBM PC or AT compatible

The EXACT run-time diskette requires a machine with a high-density diskette drive to run a delivery system (a hard-disk drive can be used). To run a consultation with the delivery version of EXACT, do the following:

1. Set the default drive of the machine to the location of the EXACT delivery system. If the machine has an A drive, type the following command and press the ENTER key:

   a:

2. Place the diskette in Drive A.

3. Type this command and press the ENTER key:

   CONSULT

Now the consultation software and the EXACT knowledge base are loaded and the consultation starts. Note that if the runtime version was installed in a hard-disk drive, you have to go the subdirectory where the runtime version was installed (use cd Dos command) and go to step 3. A detailed consultation will be presented shortly.
### 4.4 Consultation Commands

EXACT provides several commands during a consultation to help the user to control the flow of the consultation, to use the time more efficiently, and to gain additional information about the consultation. Some of these commands may help the knowledge engineer to test the knowledge base.

You can invoke the commands menu at any point during a consultation, as illustrated in Figure 4.2. To invoke the commands menu, press the F2 key, and then select one of the commands from the list that will appear. These commands and their functions are summarized below:

* **CONTINUE** - Erases the commands menu and returns the user to the consultation.

* **GET PLAYBACK FILE** - Loads a partial or complete consultation record previously saved with a SAVE PLAYBACK FILE command.

* **HOW** - Tells how EXACT has determined values for parameters other than those whose values are set by prompting the client.

* **NEW START** - Aborts the current consultation, if one is in progress, and begins a new consultation. This command is available during the consultation and at the conclusions screen.

* **PRINT CONCLUSIONS** - Prints a record of the responses to prompts during a consultation and the conclusions reached. This record provides a copy of the consultation logic for further analysis. The record can be printed to the screen, to a printer, or to a disk file, based on the user's desire.

* **QUIT** - Aborts the current consultation, if one is in progress, and returns to the activities screen.
* REVIEW - Displays the list of parameters prompted for so far in the consultation. This command allows the user to modify his/her responses and to rerun the consultation.

EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL

Conclusions:

The last comment is as follows:

This concludes this to the initial des

Commands: CONTINUE HOW TRACE ON PRINT CONCLUSIONS REVIEW SAVE PLAYBACK FILE NEW START QUIT

any modification you have made to various options.

Figure 4.2. The Commands Menu.
* **SAVE PLAYBACK FILE** - Saves a record of a partial or complete consultation.

* **TRACE ON** - Turns on the Trace feature, writing a copy of the trace file to the screen, a printer, or a disk file.

* **TRACE OFF** - Turns off the Trace feature.

* **WHY** - Explains why EXACT needs the information the user is being prompted for.

### 4.5 Graphics

IBM computers must have an Enhanced Graphics Adapter (EGA) with a color monitor or an Enhanced Color Monitor to take advantage of ESIS's graphics capabilities. A Color Graphics Adapter (CGA) or Video Graphics Array (VGA) with a color monitor would also be helpful.

### 4.6 HELP with EXACT

Any time you do not understand a prompt, you can use the HELP feature. If a parameter has a HELP property, the HELP property value appears in a window on the screen when F1 key is pressed before the client responds to the parameter's prompt. The steps of using the HELP feature at a prompt are:

1. Before responding to a prompt, press the F1 key. The HELP property value of the parameter being prompted for appears on the screen. This value may be in the form of text or a picture.

2. Now press the ENTER key. The help message will disappear.
4.7 **INPUTS and OUTPUTS of EXACT**

EXACT needs specific information (inputs) to reach a conclusion (output). The required inputs depend upon the problem characteristics under investigation. If an approach has a left-turn lane, for example, EXACT will prompt the user for the left-turning volume and the lane’s type of control (i.e., protected or permitted); if the approach does not have a left-turn lane, EXACT will not ask for this information. The following is a list of inputs for an EXACT consultation session:

- Type of problem (design or operation)
- Location of the intersection
- Type of street (major or minor)
- Speed on an approach
- Grade of an approach
- Movement on an approach
- Type of left-turning movement
- Percentage of left-turning volume
- Lane width
- Traffic volume on an approach
- Pavement condition
- Stopline and curbline location
- Presence of a driveway

At the end of a consultation session, EXACT provides the user with a full conclusion--i.e., a complete solution for the studied problem. This conclusion depends on the inputs the user has provided. For instance, if the speed is greater than 35 mph, EXACT will recommend a dilemma-zone design, which is different
from a 35 mph design. The recommended conclusion (output) includes the following:

-- The type of detector
-- The detector's configuration (i.e. dimensions and distribution)
-- The detector's location
-- Type of the actuated controller unit
-- The features associated with the controller unit
-- The timing parameters (e.g., passage time, extension time, green time)

Figure 4.3 shows input and output for EXACT.

4.8 A Consultation with EXACT

Now we shall present a detailed example of a consultation with EXACT. Both input and output will be described. Suppose a four-legged isolated intersection, as shown in Figure 4.4, needs to be controlled by an actuated controller. EXACT will assist us in designing the detection system, including the selection of the actuated-controller unit, the types and locations of the detectors, and the time settings. In our example, we will design only one approach, the northbound approach.

We begin by starting PC Plus as described in the previous section. When the knowledge base screen appears, PC Plus has finished loading. The knowledge bases screen, shown in the illustration below, lists the knowledge bases in our PC Plus directory. We select the knowledge base, EXACT, with which we want to consult with. We move the cursor down to EXACT by the proper arrow key and hit the ENTER key.
Figure 4.3. Inputs and Outputs of EXACT.
Figure 4.4. An Example for a Consultation.
Now the activities screen, illustrated below, appears. At this screen the cursor is already on CONSULT. We choose CONSULT by pressing the ENTER key. EXACT will take a few seconds to load the appropriate files, during which time the following message will appear:

One Moment Please ...
Now the Current Objectives screen, shown next, appears, and the consultation begins. The Current Objective screen describes the purpose of EXACT. Once we have read the text on this screen, we press the ENTER key.

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

Current objective:

Expert System Actuated Control for Traffic at Isolated Signalized Intersections

(EXACT)

This Expert System helps you select a detector type, location, and timing parameters of a traffic-actuated controller unit at isolated intersections.

This Expert System for Isolated Signalized Intersections (EXACT) is based on engineering expertise obtained from experts in Columbus, Ohio.

---R E D--- ---YELLOW--- ---GREEN---

** End - press ENTER to continue.**
The first prompt appearing after the Current Objective screen is:

*Select the type of problem you want to solve.*

We select the DESIGN choice, shown in the next figure, and hit the ENTER key.

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

Select the type of problem you want to solve:

- DESIGN
- OPERATION

1. Use arrow key or first letter of item to position the cursor.
2. Press ENTER to continue.
Selecting DESIGN in the previous screen takes us to the DESIGN subframe, and another Current Objective screen, shown next, explains what this subframe is about. We press the ENTER key after we have read it.

EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL

Current objective:  

THE DESIGN OF EACH APPROACH

EXACT is developed to design each approach individually. After prompting you for certain information regarding an approach, EXACT will produce a conclusion for that approach. That is, you need to enter data for each approach of your intersection separately. This stage is called the INITIAL DESIGN stage. The system will allow you to modify this initial design if you need to do so.

** End - press ENTER to continue.**
Now a screen with the following prompt appears:

*Select the area type where this intersection is located (Press F1 for Help):*

We need to press F1 for help in order to understand the choices of this prompt. The screen of this prompt and its help statement are shown in the next figure.

```
EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL

Select the the type of area where this intersection is located (F1 for Help):

<table>
<thead>
<tr>
<th>TYPE_I</th>
<th>TYPE_II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Help:
- Behaviors of drivers can be studied through this parameter.
- Type_I includes business, CBD (Central Business District), fringe, and urban (none of the previous areas.)
- Type_II includes industrial, school, and rural areas and areas with a high % of trucks.

**End - press ENTER to continue.**

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
```
Once we have made our selection and hit the ENTER key, the following prompt will appear:

*What type of street is this approach?*

This prompt is provided with a HELP statement to assist us in identifying the type of street, so we just press F1. The next figure shows this prompt.

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

What type of street is this approach?

- MAJOR
- MINOR

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
After we have selected the type of the street and hit the ENTER key, the following prompt will appear, as shown in the figure below:

*What is the speed limit on this approach? (MPH)*

We make our selection and press the ENTER key.

![Figure showing the prompt and options for speed limit]

1. Use arrow key or first letter of item to position the cursor.
2. Press ENTER to continue.
The grade of the approach should be determined in the following screen, shown next, which has the following prompt:

*Select the grade of this approach*

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

Select the grade of this approach (Press F1 For Graphic Help):

- <=5%_LEVEL
- >5%_UP
- >5%_DOWN

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
After selecting the grade and pressing the ENTER key, the following prompt will appear:

What is the type of movement on this approach?

This screen lists codes for the most typical movements in real life. We must press F1 to show these codes graphically, as shown in Figure 3.3. We select the appropriate code and hit ENTER. The screen of this prompt is presented below.

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

What is the type of movement on this approach? (Press F1 for HELP)

<table>
<thead>
<tr>
<th>Code</th>
<th>Movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>LATT</td>
</tr>
<tr>
<td>TL</td>
<td>LATTR</td>
</tr>
<tr>
<td>TR</td>
<td>LLTR</td>
</tr>
<tr>
<td>LTR</td>
<td>TTTTR</td>
</tr>
<tr>
<td>TT</td>
<td>LTTTTR</td>
</tr>
<tr>
<td>LTT</td>
<td>LATTTTR</td>
</tr>
<tr>
<td>LATR</td>
<td>LLTTR</td>
</tr>
<tr>
<td>LTTTR</td>
<td>LTTTAR</td>
</tr>
<tr>
<td>TTR</td>
<td>LATTAR</td>
</tr>
<tr>
<td>TAR</td>
<td>TTTTTR</td>
</tr>
<tr>
<td>LTAR</td>
<td>LTTTTTR</td>
</tr>
<tr>
<td>TTT</td>
<td>LATTTTTR</td>
</tr>
<tr>
<td>LTT</td>
<td>LLTTTR</td>
</tr>
<tr>
<td>TTTT</td>
<td>LTTTTR</td>
</tr>
<tr>
<td>LTTT</td>
<td>LATTTAR</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. Press ENTER to continue.
Since our approach includes a left-turn lane, the following prompt, regarding the type of control, appears:

*What type of left-turn movement do you have on this approach?*

We select PERMITTED and hit the ENTER key. The screen for this prompt is shown below.

<table>
<thead>
<tr>
<th>EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What type of Left Turn movement do you have on this approach?</strong></td>
</tr>
<tr>
<td>PROTECTED</td>
</tr>
<tr>
<td>PERMITTED</td>
</tr>
<tr>
<td>PROTECTED/PERMITTED</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
Now the following prompt, regarding the left-turning volume, appears:

What is the left-turn % for the peak-hour volume on this approach?

We select $>5\%$ and press the ENTER key. This screen is shown next.

<table>
<thead>
<tr>
<th>What is the left-turn percentage for the peak-hour volume on this approach?</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=5%</td>
</tr>
<tr>
<td>&gt;5%</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
Now this prompt appears:

What is the width of the first lane from the curb?

The width of this lane is 17 ft., but we have two choices only. We select 11 ft. (later the MODIFICATION module will modify this for us). We hit the ENTER key. The screen is shown below:

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

What is the width of the first lane from the curb (ft.)?

11
12

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
Since the approach has two lanes, another prompt for the other lane width appears, as shown in the next figure:

*What is the width of the second lane from the curb?*

We select 12 ft. and press the ENTER key.

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

**What is the width of the second lane from the curb (ft.)?**

11
12

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
The next prompt concerning the volume appears:

*What is the 15-minute peak-hour volume for the through movement?*

We type 300 and hit the ENTER key. The screen presents the following figure:

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

What is the 15-minute peak-hour volume for the through movement?

300

1. Enter a positive number.
2. press ENTER to continue.
The next screen, the conclusion screen of the DESIGN subframe, presents the initial design for this approach. It includes the types of detectors, their configurations, the controller type and its features, and the required time settings, as shown in the following figure.

<table>
<thead>
<tr>
<th>Conclusions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector type is as follows: The recommended detector types for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.</td>
</tr>
<tr>
<td>CONFIGURATION: Two PROBES are needed for the through lane and should be located 110 ft. behind the stopline. For the left-turn lane a 6' x 25' LOOP detector should be placed at the stopline. The head of the loop should be extended 5' ahead of the stopline.</td>
</tr>
<tr>
<td>RECALL: ON</td>
</tr>
<tr>
<td>MEMORY: ON</td>
</tr>
<tr>
<td>The PASSAGE TIME is given, but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:</td>
</tr>
<tr>
<td>2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.</td>
</tr>
<tr>
<td>The Minimum Green Time Setting is as follows: 20 sec.</td>
</tr>
<tr>
<td>MAX I Green Time is as follows: 70.</td>
</tr>
<tr>
<td>MAX II is as follows: 90.</td>
</tr>
<tr>
<td>Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case</td>
</tr>
<tr>
<td>The recommended type of controller is as follows: A Full-Actuated Controller Unit</td>
</tr>
</tbody>
</table>

** End - press ENTER to continue.**
After the conclusion screen, we press the ENTER key. The following prompt appears:

*Would you like to design the next approach?*

In our example we select NO and press the ENTER key. (Otherwise, the YES choice would lead us through the DESIGN subframe again to design other approaches). The following screen shows this prompt.

```
EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL

would you like to design the next approach?

YES
NO

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
```
Now we have completed the initial designing stage, and EXACT takes us to the MODIFICATION subframe to modify our initial design, as explained in Chapter 3. The modification stage begins with an introductory screen, which describes what the user can modify in this stage of the program. The next figure shows this screen.

**End - press ENTER to continue.**
When we press the ENTER key, the following prompt, shown in the next figure, appears:

_**Do you have lane width(s) other than 11 or 12 ft.? **** Recall that the initial design was based on 11 and 12 ft. lanes.**_

Since our approach has a through lane with a width of 17 ft., we respond with YES and hit the ENTER key.
The next screen provides a list of choices for lane width, and the following prompt appears:

*What is the width of the lane?*

We select 17 ft. and press the ENTER key.

<table>
<thead>
<tr>
<th>What is the width of a lane?</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
The next screen, shown in the next figure, prompts us for the pavement condition:

*Could a problem with the pavement prevent the installation of a detector?*

We respond with NO and hit the ENTER key.

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

Could a problem with the pavement prevent the installation of a detector?

**YES**

**NO**

1. Use arrow key or first letter of item to position the cursor.
2. Press ENTER to continue.
A new prompt appears, as shown in the figure below:

*Is there a driveway within 200 ft. from the intersection?*

We answer YES and press the ENTER key.

---

EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL

<table>
<thead>
<tr>
<th>Is there a driveway within 200 ft. from the intersection?</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
</tr>
<tr>
<td>NO</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. Press ENTER to continue.
Two prompts about the stopline location appears. The first is:

*Is the distance between the stopline and the curbline other than 20 ft.?*

Select YES, as shown in the figure below.

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

<table>
<thead>
<tr>
<th>Is the distance between the stopline and the curbline other than 20 ft.?</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
The second prompt is:

*What is the distance between the stopline and the curbline or edge of pavement?*

The screen of this prompt, as shown in the next figure, has a list of eight choices. We press F1 for a graphic help. We select the choice of 21-25 based on the problem data, and hit the ENTER key.

```
<table>
<thead>
<tr>
<th>What is the distance between the stopline and the curb line or edge of pavement?</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;=15</td>
</tr>
<tr>
<td>16-20</td>
</tr>
<tr>
<td>21-25</td>
</tr>
<tr>
<td>26-30</td>
</tr>
<tr>
<td>31-35</td>
</tr>
<tr>
<td>36-40</td>
</tr>
<tr>
<td>41-45</td>
</tr>
<tr>
<td>&gt;45</td>
</tr>
</tbody>
</table>

1. Use arrow key or first letter of item to position the cursor.
2. Press ENTER to continue.
```
Now the modified conclusion appears. Notice that the inputs we have changed in
the modification stage lead to different conclusions this time from the conclusions
in the initial design. For instance, the initial design recommended two probes per
lane. However, since the lane width is 17 ft., the recommended number of probes
now is four. The conclusion at the end of this session also presents a design
recommendation for the stopline location and the presence of a driveway, as shown
in the figure shown in the next page.
Conclusions: 

The dimension of detectors with respect to lane width is as follows: For the LOOP design you will need a 6'x 6'x 25' quadrupole loop. This design will leave 2.5' between the edge of the loop and the lane line to avoid interference with adjacent traffic. For the PROBE design four probes are adequate.

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: There are two cases:

1. If the driveway abuts a MAJOR street, the design should be left as recommended, but the RECALL feature in the controller unit must be ON.

2. If the driveway abuts a MINOR street, the design will depend on the detection type:
   i) For presence detection leave the loop at the stopline.
   ii) For pulse detection (probes or small loops) detectors can be placed before the driveway, but you need to place a loop before the stopline as well so that the vehicles coming out of the driveway can be detected. This situation usually occurs on minor high speed approaches.

The modification of the stopline location is as follows: The front of the loop should be extended 8 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

**End - press ENTER to continue.**
After the conclusions screen, the following prompt, shown in the figure below, will appear:

*Would you like to go over the modification stage again?*

We answer NO and hit the ENTER key. (Otherwise, we would have to go over the modification subframe again.)

---

**EXACT: EXPERT SYSTEM FOR ACTUATED CONTROL**

Would you like to go over the modification stage again?

YES
NO

1. Use arrow key or first letter of item to position the cursor.
2. press ENTER to continue.
Now a screen informs us that the session is over, as shown below. When we press the ENTER key, a commands menu shows up on this screen, as illustrated in the figure in the next page. As explained before, the commands menu provides you with several options. For example, to print the conclusions of our session, we select the PRINT CONCLUSION command by moving the cursor down to this command and pressing the ENTER key.

---

**End - press ENTER to continue.**

---

**Conclusions:**

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.
Conclusions:

The last comment is as follows:

This concludes the initial design

Commands:  
CONTINUE
HOW
TRACE ON
PRINT CONCLUSIONS
REVIEW
SAVE PLAYBACK FILE
NEW START
QUIT

any modification you have made to the various options.
If the PRINT CONCLUSION command is selected, a full conclusion output along with a consultation record will be produced. The consultation record is presented below.

Consultation record:

Consultation log: EXACT: Developed a...:
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either major or minor :: MAJOR
speed on this approach :: <=35
the grade of this approach :: <=5%_LEVEL
the movement on this approach :: LATR
The left turn movement :: PERMITTED
What is the left-turn % for the peak... :: >5%
The width of the first lane :: 11
the width of the second lane :: 11
The volume on this approach :: 300
2:four approach subframe :: NO
Modification for lane width :: YES
The width of the lane ? :: 17
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: YES
The distance between the curbline an... :: YES
the location of stopline :: 21-25
2:the unusual conditions :: NO
CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

We achieved the main objective of this research through the development of EXACT in order to assist traffic engineers to select:

1. an appropriate type of actuated signal controller and its features, typically including MEMORY, RECALL, and EXTENSION.

2. the appropriate time settings (i.e., the initial green time, the passage time, and the maximum green time -- MAX I and MAX II) for the actuated controller. These time settings should enhance the operational performance at isolated intersections.

3. the detector system, including the type of detector, its placement, and its configuration (i.e., the dimension for a loop detector and the number of detectors for a magnetometer or a magnetic detector).

This research has reached two conclusions that could have an impact on traffic-actuated control at isolated intersections. First, we have developed guidelines to assist traffic engineering practitioners in the selection of: 1) the detector type, its placement, and its dimension, 2) the actuated controller features, and 3) the time settings. Second, we have implemented these guidelines through an expert system called EXACT. That is, human expertise in the field of traffic-actuated control has been modeled by the use of artificial intelligence (i.e., an expert system) so that it
can be utilized by others. The following sections describe briefly the reasons why this expert system was used in this research, EXACT's operation, its advantages over existing computer models, and, finally, its testing results.

EXACT was used in this research to ease the problem of designing traffic-actuated control. In our research we found that to traffic practitioners, making selections is a complex process due to several factors, such as the wide range of geometric configurations for isolated intersections, the variations among drivers from one area to another, and the rapid state-of-the-art changes in traffic-actuated equipment. The research literature revealed that most local agencies of transportation have their own guidelines based on their practitioners. In other words, the problem of selecting the appropriate traffic-actuated control at isolated intersections tends to be a heuristic problem, and because of its complexity and the many qualitative factors involved, it is hard to solve algorithmically. Hence, if expert systems technology could devise standard guidelines for selecting the appropriate control, the complexity of the problem would be greatly reduced.

EXACT requires specific information from the user regarding the geometric features and traffic characteristics at a particular intersection. After receiving this information, EXACT provides a complete solution for detector type, placement, dimensions, controller features, and time settings. The system has a user-friendly inference mechanism so that the user can get textual or graphic help during a consultation. The run-time version of EXACT should be used in IBM or IBM-compatible machines. Therefore, the system can be easily transferred to different places with no need for sophisticated computer hardware.
EXACT has the following advantages over existing computerized traffic models:

-- Unlike other models, EXACT not only handles signal timing but also generates a complete solution for traffic-actuated control at isolated intersections, including the type of controller and its features, the type of detector and its configuration, and the related time settings.

-- EXACT's highly-interactive capability with the user makes it more friendly than other models. It is a menu-driven program that converses with the user through screen prompts.

-- Unlike black-box programming, EXACT is transparent. That is, it can explain its reasoning process through why/how queries from the user.

The testing and the evaluation of EXACT's performance were main phases in the system's development. EXACT was continuously tested by the knowledge engineer and the Columbus expert. From the early stages of developing the system, the knowledge engineer tested the logic structures of the knowledge base and of its inference mechanism in order to make sure that EXACT was producing the expected goals. Meanwhile, the expert was involved in the testing stage to ensure a high degree of consistency between EXACT's solutions and his own. As mentioned in the testing stage in Chapter Three, in ten real-life cases our expert agreed wholly or partially with EXACT's designs more than ninety percent of the time. Finally, EXACT was presented to two experts from Cincinnati for testing. Although these experts were not involved in the previous development of EXACT, the percentage of agreement was very encouraging: the experts agreed almost eighty percent of the time with the system's solutions. Note that the author has modified EXACT based on the experts' suggestions.
In conclusion, EXACT was designed for a certain population of users, namely, traffic engineers who have the basic knowledge of traffic-actuated control. Yet EXACT can also benefit experts in the field by exposing them to each other's expertise. Additionally, the system can be used as a learning tool for graduate students in schools teaching traffic-actuated control. EXACT would give those students a real sense of actuated-control functions.

5.2 Recommendations

As mentioned previously, EXACT was developed from one engineer's expertise in Columbus, Ohio. Therefore, we expect that EXACT's implementation will be limited to some extent. From our contact during the testing stage with experts in Cincinnati, we learned that not all local agencies use the same type of equipment. Different manufacturers may provide different features, which in turn affect the practice of traffic engineers. Also, we learned that different economic perspectives from one agency to another affect an engineer's practice. Hence, from our experience in the development of EXACT, we make the following recommendations for future research:

1. Ask experts from various cities to test the system. Then modify EXACT based on other cities' expertise. However, the area of traffic-actuated control at isolated intersections has common aspects everywhere; therefore, most likely the modification of EXACT to cover such expertise will not be substantial. The system was designed to contain the foundation of the main aspects of actuated control and to accommodate modification for expertise from experts in different cities with different conditions. For example, unlike in Columbus, experts in Los Angeles are
exposed to design conditions, which do not exist in Columbus, such as approaches with three-left-turn lanes.

2. Employ the latest computer technology in revising with EXACT.

Recently, the technology of computer-based communication has been introduced in the area of actuated signal control at isolated intersections. A computer's modem can be established in the cabinet of the actuated-controller unit to assist the traffic engineer in monitoring traffic movement at a particular intersection. The engineer can receive real-time data and respond by changing time settings in the controller unit to fit the traffic demand on any approach. This new technology could change the expertise in this field, but EXACT is so versatile that it can be modified for this change in technology.

3. Study how to implement a universal vocabulary for the field of traffic-actuated control. From the experience of conducting this research, we have observed that there is no universal vocabulary, making for confusion among researchers. We found this lack in both the literature as well as our discussions with different experts. Although NEMA (National Electrical Manufactures Association) has been a reference for standard equipment terms, many manufacturers have developed their own terms. For example, the term "small loop" has been defined differently in the literature: 6' x 6', 6' x 20', and so on. The same holds true for the term "long loop." That is, the shortness of "short" and the length of "long" are ambiguous. Another example is "passage time." We found more than four terms for this concept. A universal vocabulary, using one term for each concept, would greatly facilitate future research.
In summary, as a result of the research performed in this dissertation, we have developed an expert system, EXACT, that should provide considerable aid to traffic practitioners in the complex process of designing actuated control at isolated intersections. Through EXACT, a traffic practitioner can design numerous approaches simply by entering the required data into the computer. User-friendly EXACT not only provides conclusions, but it also explains to the practitioner the reasons for these conclusions as well as the methods by which the conclusions were reached. Although incorporating expertise from experts in cities around the country would improve the applicability of EXACT, it has already been tested by experts and found to be a reliable tool for the traffic practitioner. Knowledge detailed in this dissertation should be valuable to continued research in the area of traffic-actuated control for many years to come.
REFERENCES


APPENDIX A: EXACT's Parameters
DOMAIN :: "EXACT: Developed at The Ohio State University"
ROOT FRAME :: TRAFFIC

---------------------------
Global KB data
---------------------------

FRAME STRUCTURE ::
  TRAFFIC
  DESIGN
  MODIFICATION
  OPERATING

KB Files :: (DESIGN EXACT.k3 MODIFICATION EXACT.k2 OPERATING EXACT.k1)
Parameter groups :: (OPERATING-PARMS MODIFICATION-PARMS DESIGN-PARMS
  TRAFFIC-PARMS )
Rule groups :: (OPERATING-RULES MODIFICATION-RULES DESIGN-RULES
  TRAFFIC-RULES META-RULES )
Number of rules :: 206
Number of meta-rules :: 0
Variables :: ($$TITLE DOMAIN)
TEXTAGS :: ()
Functions :: ()
This Expert System helps you select a detector type, location, and timing. It parameters of a traffic-actuated controller unit at isolated intersections. This Expert System for Isolated Signalized Intersections (ESIS) is based on engineering expertise obtained from experts in Columbus, Ohio.

DisplayResults: Yes
ParmGroup: TRAFFIC-PARMS
RuleGroups: (TRAFFIC-RULES)
Offspring: (DESIGN MODIFICATION OPERATING)
Traffic-PARMS: (CONCLUSION DEMOGRAPHY GEOMETRY MACHINE NUSUAL OPERATE OPERATION PROBLEM RESULT ROAD SAFE TRAFFIC1 TYPE TYPE3 VOLUME)
Traffic-RULES: (RULE006 RULE145)
TRANSLATION :: (the location of the given intersection)
PROMPT :: ("Select the the type of area where this intersection is located (F1 for") :LINE "Help) :"
TYPE :: SINGLEVALUED
EXPECT :: (TYPE_I TYPE_II)
USED-BY :: (RULE014 RULE024 RULE030 RULE031 RULE022 RULE012)
HELP :: ("Behaviors of drivers can be studied through this" :LINE "parameter.") :LINE 2 "Type I includes business, CBD (Central Business) Type ":LINE " District), fringe, and urban (none of the"
"previous areas.") :LINE 2 "Type II includes industrial, school, and rural" :LINE " areas and areas
with a high % of trucks.")

GEOMETRY
TRANSLATION :: (the geometrical type of the intersection)
PROMPT :: ("select the geometrical type of the intersection from the following list:")
TYPE :: SINGLEVALUED
EXPECT :: (FOUR-APPROACH THREE-APPROACH)

MACHINE
TRANSLATION :: (operating problems associated with equipment)
PROMPT :: ("Select the problem associated with equipment")
TYPE :: SINGLEVALUED
EXPECT :: (WEATHER POWER OUTAGES TREES HORIZONTAL_CURVES CB_EQUIPMENT)
USED-BY :: (RULE170 RULE173)

NUSUAL
TRANSLATION :: (unusual conditions)
PROMPT :: (Do you want to consider unusual conditions?)
TYPE :: YES/NO

OPERATE
TRANSLATION :: (The operation conclusion)
TYPE :: SINGLEVALUED

OPERATION
TRANSLATION :: (operational problems)
PROMPT :: ("Select the operational-type problem you want to solve:")
TYPE :: SINGLEVALUED
EXPECT :: (TRAFFIC EQUIPMENT)
USED-BY :: (RULE172 RULE169 RULE171 RULE170 RULE173 RULE177 RULE178 RULE179 RULE183 RULE184 RULE176)

PROBLEM
TRANSLATION :: (The problem to be studied)
PROMPT :: ("Select the the type of problem you want to solve:")
TYPE :: SINGLEVALUED
EXPECT :: (DESIGN OPERATION)
USED-BY :: (RULE075 RULE076 RULE078 RULE087 RULE077 RULE081 RULE098 RULE103 RULE121 RULE124 RULE126 RULE127 RULE190 RULE145 RULE148 RULE151 RULE188 RULE044 RULE045 RULE047 RULE101 RULE048 RULE049 RULE052 RULE041 RULE104 RULE083)
RESULT

TRANSLATION :: (The result)
TYPE :: MULTIVALUED

ROAD

TRANSLATION :: (roadway closure)
PROMPT :: (iLINE Select the type of construction problem faced:)
TYPE :: SINGLEVALUED
EXPECT :: (LOOPS_DAMAGE DETOUR TRAFFIC_BEING_ROUTED LANE_CLOSURE SIDE_STREET_CLOSURE ROADWAY_CLOSURE)
USED-BY :: (RULE183 RULE176)

SAFE

TRANSLATION :: (operational safety problems)
PROMPT :: (iLINE What type of operational safety problems is faced ?)
TYPE :: SINGLEVALUED
EXPECT :: (ACCIDENTS CB-DAMAGE)
USED-BY :: (RULE177 RULE178 RULE179)
HELP :: ("CB_DAMAGE = Cabinet Box-Related accidents causing heavy damage on this box.")

TRAFFIC

TRANSLATION :: (operating problems regarding traffic)
PROMPT :: (iLINE Select the type of operation problem :)
TYPE :: SINGLEVALUED
EXPECT :: (CONSTRUCTION CONGESTION SAFETY)
USED-BY :: (RULE177 RULE178 RULE179 RULE183 RULE184 RULE176)

TYPE

TRANSLATION :: (The last notice)
TYPE :: SINGLEVALUED

TYPE3

TRANSLATION :: (The modification of the stopline location)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE060 RULE206 RULE061 RULE062 RULE063 RULE110 RULE193 RULE194 RULE007)

VOLUME

TRANSLATION :: (An Average Daily Traffic Volume (ADT) on this approach)
PROMPT :: ("What is the Average Daily Traffic Volume (ADT) on this approach ?")
TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
RANGE :: (200 2000)
Frame : DESIGN

IDENTIFIER : DESIGN-
TRANSLATION : (four approach subframe)
PARENTS : (TRAFFIC)
GOALS : (EQUIP PASSAGE MINGREEN TIME3 TIME2 TIME1 TYPE2)
INITIALDATA : (DEMOGRAPHY STREET SPEED GRADE)

PROMPTEVER : (:LINE " :ATTR (RED) "THE DESIGN OF EACH APPROACH" :LINE 3 :ATTR (YELLOW HIGH) "EXACT is developed to design each approach individually. After prompting you" :LINE "for certain information regarding an approach, EXACT will produce a" :LINE "conclusion for that approach. That is, you need to enter data for each" :LINE "approach of your intersection separately." :ATTR (WHITE HIGH) "This stage is called the INITIAL" :LINE "DESIGN stage. The system will allow you to modify this initial design if you" :LINE "need to do so."
)

PROMPT2ND : (would you like to design the next approach?)
DISPLAYRESULTS : YES
PARMGROUP : DESIGN-PARMS
RULEGROUPS : (DESIGN-RULES)

DESIGN-PARMS : (DELAY1 DILEMA EQUIP GRADE HEAVY LEFT LEFTTURN LGREEN MINGREEN MOVE1 PASSAGE SPEED SPEED1 STOPLINE STREET TIME TIME1 TIME2 TIME3 TIMING TYPE2 TYPES VOLUME1 VOLUME2 WIDTH WIDTH1 WIDTH2 WIDTH3 WIDTH4 WIDTH5 )

DESIGN-RULES : (RULE009 RULE010 RULE012 RULE014 RULE022 RULE024 RULE030 RULE031 RULE041 RULE042 RULE043 RULE044 RULE045 RULE046 RULE047 RULE048 RULE049 RULE050 RULE052 RULE067 RULE068 RULE069 RULE070 RULE071 RULE072 RULE073 RULE074 RULE075 RULE076 RULE077 RULE078 RULE079 RULE080 RULE081 RULE083 RULE084 RULE085 RULE086 RULE087 RULE088 RULE089 RULE090 RULE091 RULE092 RULE093 RULE094 RULE095 RULE097 RULE098 RULE099 RULE100 RULE101 RULE102 RULE103 RULE104 RULE105 RULE106 RULE107 RULE108 RULE109 RULE110 RULE111 RULE112 RULE113 RULE114 RULE115 RULE116 RULE117 RULE118 RULE119 RULE120 RULE121 RULE122 RULE123 RULE124 RULE125 RULE126 RULE127 RULE128 RULE129 RULE130 RULE131 RULE132 RULE133 RULE134 RULE135 RULE136 RULE137 RULE138 RULE139 RULE140 RULE141 RULE142 RULE143 RULE144 RULE145 RULE146 RULE148 RULE150 RULE151 RULE152 RULE153 RULE154 RULE155 RULE156 RULE157 RULE158 RULE159 RULE160 RULE161 RULE162 RULE163 RULE164 RULE165 RULE166 RULE167 RULE168 RULE169 RULE170 RULE171 RULE172 RULE173 RULE174 RULE175 RULE176 RULE177 RULE178 RULE179 RULE180 RULE181 RULE182 RULE183 RULE184 RULE185 RULE186 RULE187 RULE188 RULE189 RULE190 RULE191 RULE192 RULE193 RULE194 RULE195 RULE196 RULE197 RULE198 RULE199 RULE200 RULE201 RULE202 RULE203 RULE204 RULE205 )

FUNCTION : DATA

DELAY1

TRANSLATION : (The Detector Delay Timing)
TYPE : SINGLEVALUED

DILEMA
TRANSLATION :: (The design considering dilemma zone)
TYPE :: SINGLEVALUED

EQUIP

TRANSLATION :: (detector type)
TYPE :: SINGLEVALUED

UPDATED-BY :: (RULE075 RULE076 RULE078 RULE087 RULE077 RULE081 RULE098
RULE103 RULE121 RULE124 RULE126 RULE127 RULE190 RULE186
RULE044 RULE045 RULE047 RULE101 RULE048 RULE049 RULE052
RULE041 RULE042 RULE104 RULE083 RULE050 RULE095 RULE187
RULE098 RULE080 RULE150 RULE067 RULE068 RULE122 RULE043
RULE146 RULE084 RULE086 RULE069 RULE085 RULE087
RULE102 RULE100 RULE199 RULE097 RULE152 RULE198 RULE200
RULE203 RULE182 RULE180 RULE181 RULE202 RULE187 RULE119
RULE112 RULE073 RULE074 RULE111 RULE153 RULE154 RULE118
RULE114 RULE116 RULE115 RULE112 RULE157 RULE158 RULE159
RULE161 RULE123 RULE204 RULE125 RULE160 RULE113 RULE163
RULE165 RULE167 RULE168 RULE205 RULE079 RULE046 )

GRADE

TRANSLATION :: (the grade of this approach)
PROMPT :: ("Select the grade of this approach (Press F1 For Graphic Help):")
TYPE :: SINGLEVALUED
EXPECT :: (<-5%_LEVEL >5%_UP >5%D_DOWN)
USED-BY :: (RULE014 RULE024 RULE030 RULE031 RULE022 RULE012)

HEAVY

TRANSLATION :: (Percentage of heavy vehicles on this approach)
PROMPT :: (What is the percentage of Heavy vehicles on this approach?)
TYPE :: SINGLEVALUED
EXPECT :: (<5% >5%)
HELP :: ("percentage of heavy vehicles on" :LINE "this" :LINE "approach." :LINE 2 "Heavy vehicles include trucks and buses." :LINE 2 "<5% is less than or equal 5 percent." :LINE 2">5% is greater than 5 percent.")

LEFT

TRANSLATION :: (What is the left-turn % for the peak-hour volume on this approach?)
PROMPT :: ("What is the left-turn percentage for the peak-hour volume on this approach?")
TYPE :: SINGLEVALUED
EXPECT :: (<5% >5%)
USED-BY :: (RULE076 RULE077 RULE098 RULE121 RULE126 RULE127 RULE045
RULE047 RULE101 RULE048 RULE041 RULE050 RULE187
RULE067 RULE068 RULE071 RULE070 RULE100 RULE199 RULE097
RULE073 RULE074 RULE116 RULE115 RULE112 RULE159 RULE161
RULE113 RULE046 )

LEFTTURN

TRANSLATION :: (The left turn movement)
PROMPT :: ("What type of Left Turn movement do you have on this approach?")
TYPE :: SINGLEVALEED
EXPECT :: (PROTECTED PERMITTED PROTECTED/PERMITTED)
USED-BY :: (RULE075 RULE076 RULE077 RULE081 RULE089 RULE102 RULE124
RULE126 RULE127 RULE044 RULE045 RULE047 RULE101 RULE048
RULE049 RULE099 RULE080 RULEC86 RULE069 RULE071 RULE085
RULE123 RULE204 RULE125 RULE160 RULE195 RULE046 )
HELP :: ("The following are WARrANTS to help you decide": LINE "whether
protected, otherwise permitted:" :LINE 2 "1. One left-turning
vehicle delayed 2 cycle or": LINE " more during a peak hour.
(Based on expertise).": LINE 2 "2. The product of left-turning
vehicles and": LINE "conflicting through vehicles during the
peak": LINE " hour is > 50,000." :LINE 2 "3. Left-turn volume
> 80 vehicles during the": LINE " peak hour." )

LGREEN

TRANSLATION :: (minimum green time for the left-turn phase)
TYPE :: SINGLEVALEED

MINGREEN

TRANSLATION :: (The Minimum Green Time Setting)
TYPE :: SINGLEVALEED
UPDATED-BY :: (RULE130 RULE131 RULE132 RULE197 RULE201 RULE202)

MOVE1

TRANSLATION :: (the movement on this approach)
PROMPT :: ("What is the type of movement on this approach ? (Press F1
for HELP)"
TYPE :: SINGLEVALEED
EXPECT :: (T TL TR LTR PT LIT LATR LTTT TR LTR TAR LITAR LTT LTTT TTR
LTTTTR LATTT TR LIT LTTTTR LATTTR LATTTT TR LATTTR LTTTR )
USED-BY :: (RULE075 RULE076 RULE078 RULE087 RULE077 RULE098
RULE103 RULE121 RULE124 RULE126 RULE127 RULE190 RULE148
RULE151 RULE158 RULE044 RULE045 RULE047 RULE101 RULE048
RULE049 RULE052 RULE041 RULE042 RULE104 RULE083 RULE050
RULE095 RULE187 RULE099 RULE080 RULE150 RULE067 RULE068
RULE122 RULE043 RULE146 RULE084 RULE086 RULE069 RULE071
RULE085 RULE070 RULE102 RULE100 RULE199 RULE097 RULE152
RULE132 RULE197 RULE201 RULE202 RULE138 RULE200 RULE203
RULE182 RULE180 RULE181 RULE072 RULE117 RULE119 RULE120
RULE073 RULE074 RULE111 RULE153 RULE154 RULE118 RULE114
RULE116 RULE115 RULE112 RULE157 RULE158 RULE159 RULE161
RULE123 RULE204 RULE125 RULE160 RULE123 RULE163 RULE165
RULE167 RULE168 RULE205 RULE195 RULE196 RULE079 RULE046 )
GHELP :: (move)

PASSAGE

TRANSLATION :: (The PASSAGE TIME is given but first a chart will appear
to illustrate the relationship between passage time,
grade, and the location of the intersection. This chart
is )
TYPE :: MULTIVALUED
UPDATED-BY :: (RULE014 RULE024 RULE030 RULE031 RULE088 RULE089 RULE090
RULE091 RULE092 RULE093 RULE022 RULE012 )
SPEED

TRANSLATION :: (speed on this approach)
PROMPT :: (What is the speed limit on this approach? (MPH))
TYPE :: SINGLEVALUED
EXPECT :: (< 35 > 35)
USED-BY :: (RULE075 RULE076 RULE078 RULE087 RULE095 RULE105)

HELP :: (:LINE "Speed of 35 mph is believed by our expert as"
well as most of the literature as the break":LINE "point between Low and High speed approaches." :LINE 2 "- Consequently, dilemma-zone considerations are":LINE "taken for approaches with speed greater":LINE "than 35 mph in this system." )

SPEED1

TRANSLATION :: (The speed of the high speed approach)
PROMPT :: (What is the exact speed limit on this high-speed approach?)
TYPE :: SINGLEVALUED
EXPECT :: (40 45 50 55 60 65)
USED-BY :: (RULE080 RULE095 RULE105 RULE092 RULE093)

STOPLINE

TRANSLATION :: (the location of stopline)
PROMPT :: (What is the distance between stopline and the curb line or edge of pavement?)
TYPE :: SINGLEVALUED
EXPECT :: (> 5 10 15)
HELP:
"The following criteria will help you determine": LINE "major or minor street": LINE 2 "1. VOLUME: If ADT volume of street A is greater": LINE " than or equal to 1000 vph over street B, then": LINE " street A is Major and street B is Minor.".

2. SPEED: If volume criterion is not satisfied, consider the speed limits. If the speed limit of street A is greater than speed limit of street B then street A is Major and".

3. If VOLUME and SPEED criteria are not satisfied".

TIME

TRANSLATION: (Maximum green time for the through phase in sec.; MAX I)

TYPE: MULTIVALUED

UPDATED-BY:

RULE119 RULE120 RULE073 RULE074 RULE111 RULE153 RULE154
RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158
RULE159 RULE161 RULE123 RULE204 RULE125 RULE160 RULE113
RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046

CONTAINED-IN:

RULE188 RULE044 RULE045 RULE047 RULE101 RULE048
RULE049 RULE052 RULE041 RULE104 RULE083 RULE050
RULE095 RULE187 RULE099 RULE080 RULE150 RULE067
RULE122 RULE043 RULE146 RULE080 RULE096 RULE071
RULE085 RULE070 RULE102 RULE100 RULE199 RULE097
RULE198 RULE200 RULE123 RULE182 RULE180 RULE181
RULE117 RULE119 RULE120 RULE073 RULE111 RULE153
RULE154 RULE118 RULE114 RULE116 RULE115 RULE127
RULE152 RULE197 RULE201 RULE202 RULE200 RULE203
RULE182 RULE180 RULE181 RULE072 RULE114 RULE158
RULE120 RULE073 RULE074 RULE111 RULE153 RULE154
RULE119 RULE114 RULE116 RULE115 RULE112 RULE157
RULE158 RULE159 RULE161 RULE123 RULE204 RULE160
RULE113 RULE163 RULE165 RULE167 RULE168 RULE205
RULE079 RULE046

TIME1

TRANSLATION: (Maximum green time of the left-turn phase in sec.)

TYPE: SINGLEVALUED

UPDATED-BY:

RULE075 RULE081 RULE103 RULE124 RULE099 RULE086 RULE069
RULE102 RULE152 RULE132 RULE197 RULE201 RULE202 RULE198
RULE200 RULE203 RULE182 RULE180 RULE181 RULE114 RULE158
RULE123 RULE204 RULE167 RULE168 RULE205 RULE195 RULE196

TIME2
TRANSLATION :: (MAX I)
TYPE :: SINGLEVALEOED
UPDATED-BY :: (RULE188 RULE044 RULE045 RULE047 RULE101 RULE048 RULE049 RULE052 RULE041 RULE104 RULE083 RULE050 RULE095 RULE187 RULE099 RULE080 RULE150 RULE067 RULE068 RULE122 RULE043 RULE146 RULE084 RULE086 RULE069 RULE071 RULE085 RULE070 RULE102 RULE100 RULE199 RULE097 RULE152 RULE198 RULE200 RULE203 RULE182 RULE180 RULE181 RULE072 RULE153 RULE154 RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158 RULE159 RULE161 RULE123 RULE204 RULE160 RULE113 RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046 )

TIME3

TRANSLATION :: (MAX I Green Time)
TYPE :: SINGLEVALEOED
UPDATED-BY :: (RULE188 RULE044 RULE045 RULE047 RULE101 RULE048 RULE049 RULE052 RULE041 RULE104 RULE083 RULE050 RULE095 RULE187 RULE099 RULE080 RULE150 RULE067 RULE068 RULE122 RULE043 RULE146 RULE084 RULE086 RULE069 RULE071 RULE085 RULE070 RULE102 RULE100 RULE199 RULE097 RULE152 RULE198 RULE200 RULE203 RULE182 RULE180 RULE181 RULE072 RULE153 RULE154 RULE119 RULE120 RULE073 RULE074 RULE111 RULE153 RULE154 RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158 RULE159 RULE161 RULE123 RULE204 RULE160 RULE113 RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046 )
CONTAINED-IN :: (RULE188 RULE044 RULE045 RULE047 RULE101 RULE048 RULE049 RULE049 RULE052 RULE041 RULE104 RULE083 RULE050 RULE095 RULE187 RULE099 RULE080 RULE150 RULE067 RULE068 RULE122 RULE043 RULE146 RULE084 RULE086 RULE069 RULE071 RULE085 RULE070 RULE102 RULE100 RULE199 RULE097 RULE152 RULE198 RULE200 RULE203 RULE182 RULE180 RULE181 RULE072 RULE153 RULE154 RULE119 RULE120 RULE073 RULE074 RULE111 RULE153 RULE154 RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158 RULE159 RULE161 RULE123 RULE204 RULE160 RULE113 RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046 )

TIMING

TRANSLATION :: (timing parameters)
TYPE :: SINGLEVALEOED

TYPE2

TRANSLATION :: (The recommended type of controller)
TYPE :: SINGLEVALEOED
UPDATED-BY :: (RULE009 RULE010)

TYPES

TRANSLATION :: (A notice for this approach)
TYPE :: SINGLEVALEOED

VOLUME1

TRANSLATION :: (The volume on this approach)
PROMPT :: (:LINE "What is the 15-minute peak-hour volume for the through movement?"

TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
HELP :: (:LINE "If you have the peak-hour volume you need to" :LINE "divide it by 4 to obtain the 15-minute peak?":LINE 2 "Our expert uses his own formula to obtain a":LINE "green time large enough for such a volume. This":LINE "formula is:" :LINE 2 "Green Time = (Volume / 15) * 2.5":LINE 2 "Where Volume stands for the 15-min. peak hour":LINE "volume you input and this is divided by 15 to":LINE "obtain a one-minute volume." :LINE 2 "He assumes that the average departing headway":LINE "between vehicles is 2.5 seconds."

CONTAINED-IN :: (RULE075 ROLE076 ROLE078 RULE087 RULE077 RULE081 RULE098 RULE103 RULE124 RULE126 RULE127 RULE190 RULE146 RULE151 RULE188 ROLE044 ROLE045 ROLE047 ROLE101 ROLE048 ROLE049 ROLE052 ROLE041 RULE099 RULE080 ROLE150 ROLE067 ROLE068 ROLE122 RULE043 RULE146 RULE084 RULE086 ROLE069 ROLE071 RULE085 RULE070 ROLE102 ROLE154 RULE197 ROLE201 RULE202 ROLE198 RULE200 RULE182 RULE180 RULE181 RULE072 RULE117 RULE139 RULE120 RULE073 RULE074 RULE115 RULE153 RULE118 RULE114 RULE116 RULE115 RULE152 RULE151 RULE187 RULE161 RULE123 RULE204 RULE125 RULE160 RULE113 RULE163 RULE165 RULE167 RULE205 RULE079 RULE046)

RANGE :: (1 2000)

VOLUME2

TRANSLATION :: (The peak-hour volume on the left-turn approach)
PROMPT :: (:LINE 2 "What is the 15 minute peak-hour volume on the left-turn movement?"

TYPE :: SINGLEVALUED
EXPECT :: POSITIVE-NUMBER
HELP :: (:LINE "If you have the peak-hour volume you need to":LINE "divide it by 4 to obtain the 15-min peak":LINE "volume.

CONTAINED-IN :: (RULE075 ROLE081 RULE103 RULE124 RULE099 RULE086 RULE069 RULE102 RULE152 RULE132 RULE197 RULE201 RULE202 RULE198 RULE200 RULE182 RULE180 RULE181 RULE114 RULE150 RULE123 RULE204 RULE167 RULE168 RULE205)

RANGE :: (1 2000)

WIDTH

TRANSLATION :: (the width of through lane (s))
PROMPT :: (:LINE What is the width of the through lane (ft.)?"

TYPE :: SINGLEVALUED
EXPECT :: (11 12)
USED-BY :: (RULE076 ROLE087 RULE146 RULE188 RULE041 RULE042 RULE043 RULE046 RULE203 RULE205)
HELP :: (:LINE 2 "At this prompt you have only two choices 11 or 12":LINE "ft. For other lane widths such as 9, 10, 13 ft.":LINE "and greater the MODIFICATION STAGE will permit a":LINE "different lane width to be considered. Just wait":LINE "and you will be prompt for such modifications." )
WIDTH1

TRANSLATION : : (The width of the first lane)

PROMPT : : (:LINE "What is the width of the first lane from the curb (ft.)?"

TYPE : : SINGLEVALUED

EXPECT : : (11 12)

USED-BY : : (RULE075 RULE076 RULE077 RULE081 RULE098 RULE103 RULE121
RULE124 RULE126 RULE127 RULE190 RULE151 RULE044 RULE045
RULE047 RULE101 RULE048 RULE049 RULE052 RULE083
RULE050 RULE095 RULE187 RULE099 RULE080 RULE150 RULE067
RULE068 RULE122 RULE084 RULE086 RULE069 RULE071 RULE085
RULE070 RULE102 RULE100 RULE199 RULE152 RULE198
RULE200 RULE203 RULE182 RULE180 RULE181 RULE072 RULE117
RULE119 RULE120 RULE073 RULE074 RULE111 RULE153 RULE154
RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158
RULE159 RULE161 RULE123 RULE204 RULE125 RULE160 RULE113
RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046)

WIDTH2

TRANSLATION : : (The width of the second lane)

PROMPT : : (:LINE "What is the width of the second lane from the curb (ft.)?"

TYPE : : SINGLEVALUED

EXPECT : : (11 12)

USED-BY : : (RULE075 RULE076 RULE077 RULE081 RULE103 RULE121
RULE124 RULE126 RULE127 RULE190 RULE151 RULE044 RULE045
RULE047 RULE101 RULE048 RULE049 RULE052 RULE150 RULE067
RULE068 RULE122 RULE084 RULE086 RULE069 RULE071 RULE085
RULE070 RULE102 RULE100 RULE199 RULE152 RULE198
RULE200 RULE203 RULE182 RULE180 RULE181 RULE072 RULE117
RULE119 RULE120 RULE073 RULE074 RULE111 RULE153 RULE154
RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158
RULE159 RULE161 RULE123 RULE204 RULE125 RULE160 RULE113
RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046)

WIDTH3

TRANSLATION : : (The width of the third lane)

PROMPT : : (:LINE "What is the width of the third lane from the curb (ft.)?"

TYPE : : SINGLEVALUED

EXPECT : : (11 12)

USED-BY : : (RULE075 RULE076 RULE077 RULE103 RULE121
RULE124 RULE126 RULE127 RULE190 RULE151 RULE044 RULE045
RULE047 RULE101 RULE048 RULE049 RULE052 RULE150 RULE067
RULE068 RULE122 RULE084 RULE086 RULE069 RULE071 RULE085
RULE070 RULE102 RULE100 RULE199 RULE152 RULE198
RULE200 RULE203 RULE182 RULE180 RULE181 RULE072 RULE117
RULE119 RULE120 RULE073 RULE074 RULE111 RULE153 RULE154
RULE118 RULE114 RULE116 RULE115 RULE112 RULE157 RULE158
RULE159 RULE161 RULE123 RULE204 RULE125 RULE160 RULE113
RULE163 RULE165 RULE167 RULE168 RULE205 RULE079 RULE046)

WIDTH4

TRANSLATION : : (The width of the fourth lane)

PROMPT : : (:LINE "What is the width of the fourth lane from the curb (ft.)?"

TYPE :: SINGLEVALUED
EXPECT :: (11 12)
USED-BY :: (RULE075 RULE076 RULE077 RULE121 RULE124 RULE126 RULE127 RULE120 RULE121 RULE073 RULE074 RULE111 RULE153 RULE154 RULE118 RULE114 RULE115 RULE112 RULE157 RULE158 RULE159 RULE161 RULE123 RULE204 RULE125 RULE160 RULE113 RULE163 RULE165 RULE167 RULE168 RULE205 )

WIDTH5

TRANSLATION :: (The width of the fifth lane)
PROMPT :: (:LINE "What is the width of the fifth lane from the curb (ft.) ?")

TYPE :: SINGLEVALUED
EXPECT :: (11 12)
USED-BY :: (RULE111 RULE153 RULE154 RULE116 RULE115 RULE112 RULE157 RULE158 RULE159 RULE161 RULE204 RULE160 RULE113 RULE163 RULE165 RULE167 RULE168 RULE205 )
Modification

**IDENTIFIER:** MODIFICATION-
**TRANSLATION:** (the unusual conditions)

**PARENTS:** (TRAFFIC)
**GOALS:** (DIME CONDITION DRIVE TYPE3)

**PROMPTEVER:**

```plaintext
Once the design stage is complete, EXACT will allow you to make modifications on your design. These modifications include:
- Stopline Location
- Lane Width
- Pavement Condition
- Driveway Presence

GOOD LUCK WITH YOUR SESSION
```

**PROMPT2ND:**

```plaintext
Would you like to go over the modification stage again?
```

**DISPLAYRESULTS:** YES

**PARMGROUP:** MODIFICATION-PARMS
**RULEGROUPS:** (MODIFICATION-RULES)

**MODIFICATION-PARMS:**

```plaintext
CONDITION
TRANSLATION: (The modification for pavement conditions)
TYPE: SINGLEVALUED
UPDATED-BY: (RULE192 RULE186 RULE185 RULE066)

CONSTRUCTION
TRANSLATION: (Construction at the intersection)
PROMPT: "Is there any construction on any approach(s) at the intersection?"
TYPE: YES/NO

CURB
TRANSLATION: (The distance between the curbline and the stopline)
PROMPT: (LINE 2 "Is the distance between the stopline and the curbline other than 20 ft.?"
TYPE: YES/NO
USED-BY: (RULE060 RULE206 RULE061 RULE062 RULE063 RULE110 RULE193）
```
RULE194 RULE007

DIME
TRANSLATION :: (The dimension of detectors with respect to lane width)
TYPE :: MULTIVALUED
UPDATED-BY :: (RULE189 RULE053 RULE054 RULE055 RULE056 RULE057 RULE058 RULE059)

DRIVE
TRANSLATION :: (Modification for driveway presence)
TYPE :: SINGLEVALED
UPDATED-BY :: (RULE191 RULE065)

DRIVEWAY
TRANSLATION :: (Driveway around the intersection)
PROMPT :: (:LINE "Is there a driveway within 200 ft. from the intersection?"
TYPE :: YES/NO
USED-BY :: (RULE191 RULE065)
GHELP :: (DRIVE)

INSTALLATION
TRANSLATION :: (Installation of detectors)
PROMPT :: ("Do you want to go over the installation process of detectors and its" :LINE "standards?"
TYPE :: YES/NO

LANE
TRANSLATION :: (The width of the lane?)
PROMPT :: (What is the width of a lane?)
TYPE :: SINGLEVALED
EXPECT :: (9 10 13 14 15 16 17 18 19 20)
USED-BY :: (RULE189 RULE053 RULE054 RULE055 RULE056 RULE057 RULE058)
GHELP :: (LANE1)

LANE1
TRANSLATION :: (Modification for lane width)
PROMPT :: (:LINE 2 "Do you have lane width(s) other than 11 or 12 ft.? 
***** Recall that the" :LINE "initial design was based on 11 and 12 ft. lanes."
TYPE :: YES/NO
USED-BY :: (RULE189 RULE053 RULE054 RULE055 RULE056 RULE057 RULE058 RULE059)

MIME
TRANSLATION :: (Driveway presence)
TYPE :: SINGLEVALED

PAVECOND
TRANSLATION :: (A description for pavement condition i.e. Cracks and so on.)
PROMPT :: (:LINE Select the type of pavement problems do you have:)
TYPE :: SINGLEVALUED
EXPECT :: (CRACKS POTHOLE BROKEN CORRUGATIONS)
USED-BY :: (RULE186 RULE185 RULE066)

PAVEMENT

TRANSLATION :: (pavement condition : Is there any Problem ?)
PROMPT :: (:LINE "Could a problem with the pavement prevent the installation of a detector ?")
TYPE :: YES/NO
USED-BY :: (RULE192 RULE186 RULE185 RULE066)
HELP :: (:LINE "If you select YES the system will prompt you for" :LINE "the type of the problem CRACKS, POTHOLEs, and so" :LINE "forth.")

STOPLIN

TRANSLATION :: (the location of stopline)
PROMPT :: (:LINE "What is the distance between the stopline and the curb line or edge of" :LINE "pavement?")
TYPE :: SINGLEVALUED
EXPECT :: (<=15 16-20 21-25 26-30 31-35 36-40 41-45 >45)
USED-BY :: (RULE060 RULE061 RULE062 RULE063 RULE110 RULE193 RULE194 RULE007)
HELP :: (CURB STOPLINE)
Frame :: OPERATING

IDENTIFIER :: "OPERATING-
TRANSLATION :: (This frame concerns with operational problems that the
traffic professional may face.)
PARENTS :: (TRAFFIC)
GOALS :: (RESULT3)
DISPLAYRESULTS :: YES
PARMGROUP :: OPERATING-PARMS
RULEGROUPS :: (OPERATING-RULES)
OPERATING-PARMS :: (RESULT3)
OPERATING-RULES :: (RULE169 RULE170 RULE171 RULE172 RULE173 RULE176
RULE177 RULE178 RULE179 RULE183 RULE184)

---------------------
OPERATING-PARMS
---------------------

RESULT3

TRANSLATION :: (the result of operational problems)
TYPE :: SINGLEVALUED
UPDATED-BY :: (RULE172 RULE169 RULE171 RULE170 RULE173 RULE177 RULE178
RULE179 RULE183 RULE184 RULE176)
APPENDIX  B:  EXACT's Rules
DOMAIN :: "EXACT: Developed at The Ohio State University"
ROOT FRAME :: TRAFFIC

===============================
Global KB data
===============================

FRAME STRUCTURE ::
  TRAFFIC
  DESIGN
  MODIFICATION
  OPERATING

KB Files :: (OPERATING EXACT.k1 MODIFICATION EXACT.k2 DESIGN EXACT.k3)
Parameter groups :: (OPERATING-PARMS MODIFICATION-PARMS DESIGN-PARMS
                   TRAFFIC-PARMS )
Rule groups :: (OPERATING-RULES MODIFICATION-RULES DESIGN-RULES
                TRAFFIC-RULES META-RULES )
Number of rules :: 206
Number of meta-rules :: 0
Variables :: ($$TITLE DOMAIN)
TEXTAGS :: ()
Functions :: ()
Frame :: TRAFFIC

IDENTIFIER :: "TRAFFIC-

TRANSLATION :: (the selection of detector type and location)

GOALS :: (CONCLUSION)

PROMPTEVER :: (:LINE :ATTR (MAGENTA HIGH) " Expert System

Actuated Control for Traffic at Isolated" :LINE " Signalized Intersections" :LINE 2 " (EXACT)" :LINE 2 :ATTR (CYAN HIGH ) "This Expert System helps you select a detector
type, location, and timing" :LINE "parameters of a
traffic-actuated controller unit at isolated
intersections." :LINE 2 "This Expert System for Isolated
Signalized Intersections (ESIS) is based on" :LINE "

engineering expertise obtained from experts in Columbus, Ohio." :LINE :ATTR (WHITE HIGH ) "

" :LINE "

" :ATTR (RED BLINK) "[---------[" :ATTR (GREEN HIGH BLINK ) " " :ATTR (YELLOW HIGH BLINK) "[---------[" :LINE "

" :ATTR (RED BLINK) "[---------[" :ATTR (GREEN HIGH BLINK ) "[---------[" : LINE "

" :ATTR (YELLOW HIGH BLINK) "[---------[" :ATTR (GREEN HIGH BLINK ) "[---------[" : LINE "


DISPLAYRESULTS :: YES

PARMGROUP :: TRAFFIC-PARMS

RULEGROUPS :: (TRAFFIC-RULES)

OFFSPRING :: (DESIGN MODIFICATION OPERATING)

TRAFFIC-PARMS :: (CONCLUSION DEMOGRAPHY GEOMETRY MACHINE NUSUAL OPERATE

OPERATION PROBLEM RESULT ROAD SAFE TRAFFIC1 TYPE TYPE3

VOLUME )

TRAFFIC-RULES :: (RULE006 RULE145)

RULE006

SUBJECT :: TRAFFIC-RULES

If The problem to be studied is DESIGN,

Then 1) instantiate the frame four approach subframe if appropriate, and

2) instantiate the frame the unusual conditions if appropriate, and

3) it is definite (100%) that The last comment is
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

RULE145

SUBJECT :: TRAFFIC-RULES
If The problem to be studied is OPERATION,
Then 1) instantiate the frame This frame concerns with operational problems that the traffic professional may face. If appropriate, and
2) it is definite (100%) that the last comment is

This concludes the operation session. The next menu will have various options..
IDENTIFIER :: DESIGN-

TRANSLATION :: (four approach subframe)

PARENTS :: (TRAFFIC)

GOALS :: (EQUIP PASSAGE MINGREEN TIME3 TIME2 TIME1 TYPE2)

INITIALDATA :: (DEMOGRAPHY STREET SPEED GRADE)

PROMPTEVER :: ((LINE "":ATTR (RED) "" :LINE 3 :ATTR (YELLOW HIGH) "THE DESIGN OF EACH APPROACH" :LINE 3 :ATTR (YELLOW HIGH) "EXACT is developed to design each approach individually. After prompting you":LINE "for certain information regarding an approach, EXACT will produce a":LINE "conclusion for that approach. That is, you need to enter data for each":LINE "approach of your intersection separately." :ATTR (WHITE HIGH) :ATTR (YELLOW HIGH) "This stage is called the INITIAL" :LINE "DESIGN stage. The system will allow you to modify this initial design if you":LINE "need to do so." )

PROMPT2ND :: (would you like to design the next approach?)

DISPLAYRESULTS :: YES

PARMGROUP :: DESIGN-PARMS

RULEGROUPS :: (DESIGN-RULES)

DESIGN-PARMS :: (DELAY1 DILEMA EQUIP GRADE HEAVY LEFT LEFTTURN LGREEN MINGREEN MOVE1 PASSAGE SPEED SPEED1 STOPLINE STREET TIME TIME1 TIME2 TIME3 TIMING TYPE2 TYPES VOLUME1 VOLUME2 WIDTH WIDTH1 WIDTH2 WIDTH3 WIDTH4 WIDTH5 )

DESIGN-RULES :: (RULE009 RULE010 RULE012 RULE014 RULE022 RULE024 RULE030 RULE031 RULE041 RULE042 RULE043 RULE044 RULE045 RULE046 RULE047 RULE048 RULE049 RULE050 RULE052 RULE067 RULE068 RULE071 RULE073 RULE074 RULE075 RULE076 RULE077 RULE078 RULE079 RULE080 RULE081 RULE090 RULE091 RULE092 RULE093 RULE095 RULE097 RULE098 RULE099 RULE100 RULE101 RULE102 RULE103 RULE104 RULE111 RULE112 RULE113 RULE114 RULE115 RULE116 RULE117 RULE118 RULE119 RULE120 RULE121 RULE122 RULE123 RULE124 RULE125 RULE126 RULE127 RULE130 RULE131 RULE132 RULE146 RULE148 RULE150 RULE151 RULE152 RULE153 RULE154 RULE157 RULE158 RULE159 RULE160 RULE161 RULE163 RULE165 RULE167 RULE168 RULE180 RULE181 RULE182 RULE187 RULE188 RULE190 RULE195 RULE196 RULE197 RULE198 RULE199 RULE200 RULE201 RULE202 RULE203 RULE204 RULE205 )

RULE009

SUBJECT :: DESIGN-RULES

DESCRIPTION :: (The controller type for speed <=35)

If speed on this approach is <=35,
Then it is definite (100%) that The recommended type of controller is A Full-Actuated Controller Unit.
RULE010

SUBJECT : DESIGN-RULES
DESCRIPTION : (The controller type for speed >35)
If speed on this approach is >35,
Then it is definite (100%) that The recommended type of controller is A Volume Density Controller Unit.

RULE012

SUBJECT : DESIGN-RULES
DESCRIPTION : (Passage Time)
If 1) speed on this approach is <=35, and
2) the location of the given intersection is TYPE_I, and
3) the grade of this approach is <=5% LEVEL,
Then 1) associate a picture with The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is, and
2) it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is 2.5-3.0 secs. as the value that should be set into the controller unit to ensure snappy operation..

RULE014

SUBJECT : DESIGN-RULES
DESCRIPTION : (Passage Time)
If 1) speed on this approach is <=35, and
2) the location of the given intersection is TYPE_II, and
3) the grade of this approach is <=5% LEVEL,
Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is 3.5-4.0 of passage time is the suggested range to select from. Our expert suggests 2.5 sec. as the value that should be set into the controller unit to ensure snappy operation..

RULE022

SUBJECT : DESIGN-RULES
DESCRIPTION : (Passage Time)
If 1) speed on this approach is <=35, and
2) the location of the given intersection is TYPE_I, and
3) the grade of this approach is >5% UP,
Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is 3.5-4.0 of passage time is the suggested range to select from. Our expert suggests 3.5 sec. as the value that should be set into the controller unit to ensure snappy operation..

RULE024

SUBJECT : DESIGN-RULES
DESCRIPTION : (Passage Time)

If 1) speed on this approach is <=35, and
2) the location of the given intersection is TYPE_II, and
3) the grade of this approach is >5%_UP,

Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is 4.5-5.0 of passage time is the suggested range to select from. Our expert suggests 4.5 sec. as the value that should be set into the controller unit to ensure snappy operation..

RULE030
---------
SUBJECT :: DESIGN-RULES
DESCRIPTION : (Passage Time)

If 1) speed on this approach is <=35, and
2) the location of the given intersection is TYPE_II, and
3) the grade of this approach is >5%_DOWN,

Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is 2.5-3.0 of passage time the suggested range to select from. Our expert suggests 2.5 sec. as the value that should be set into the controller unit to ensure snappy operation..

RULE031
---------
SUBJECT :: DESIGN-RULES
DESCRIPTION : (Passage Time)

If 1) speed on this approach is <=35, and
2) the location of the given intersection is TYPE_I, and
3) the grade of this approach is >5%_DOWN,

Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is 1.5-2.0 of passage time is the suggested range to select from. Our expert suggests 1.5 sec. as the value that should be set into the controller unit to ensure snappy operation..

RULE041
---------
SUBJECT :: DESIGN-RULES
DESCRIPTION : (Movement is LTR, Major, <=35 mph, and <=5% left turn.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is TL, or
2) the movement on this approach is LTR, and
5) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
6) 1) the width of through lane s is 11, or
2) the width of through lane s is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is <![The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.
CONFIGURATION: TWO PROBES are needed for this approach and should be located 110 ft. behind the stopline.

RECALL: ON
MEMORY: ON.

RULE042

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LTR, Major, Left >=5%)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is TL, or
   2) the movement on this approach is LTR, and
5) What is the left-turn % for the peak-hour volume on this approach? is >=5%, and
6) 1) the width of through lane s is 11, or
   2) the width of through lane s is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: TWO PROBES are needed for this approach and should be located 110 ft. behind the stopline.

RECALL: ON
MEMORY: ON

NOTE: A 6'x 25' LOOP should be installed at the stopline to handle the left-turning vehicles. The head of the loop should be extended 5' ahead of the stopline.

RULE043

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LTR, Minor, <=35 mph)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is TL, or
   2) the movement on this approach is LTR, or
   3) the movement on this approach is T, or
   4) the movement on this approach is TR, and
5) 1) the width of through lane s is 11, or
   2) the width of through lane s is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 10], and
4) it is definite (100%) that detector type is The recommended detector
type for this approach is a LOOP DETECTOR.

CONFIGURATION: A 6'x 25' LOOP is needed for this approach and should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON

DETECTOR TIME-DELAY = 8 sec.

RULE044

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LAT or LATR, <=35 mph, and Protected.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LAT, or
2) the movement on this approach is LATR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,
Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector types for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.

CONFIGURATION: TWO PROBES are needed for this approach. They should be located 110 ft. behind the stopline. For the left-turn lane a 6'x 20' LOOP detector should be placed 20 ft. behind the stopline; this design is considered a second car detection.

RECALL: ON
MEMORY: ON.

RULE045

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LAT or LATR, Major, <=35, perm. & prot/perm., >5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LAT, or
2) the movement on this approach is LATR, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach? is >5%, and
7) 1) The width of the first lane is 11, or  
2) The width of the first lane is 12, and  
8) 1) the width of the second lane is 11, or  
2) the width of the second lane is 12,  
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \( \left[ \frac{\text{The volume on this approach divided by 15}}{12} \right] \times 2.5 \), and  
2) it is definite (100%) that MAX I Green Time is \( \left[ \frac{\text{Maximum green time for the through phase in sec.; MAX I plus 20}}{12} \right] \), and  
3) it is definite (100%) that MAX II is \( \left[ \frac{\text{MAX I Green Time plus 20}}{12} \right] \), and  
4) it is definite (100%) that detector type is The recommended detector type for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.  

CONFIGURATION: Two PROBES are needed for the through lane and should be located 110 ft. behind the stopline. For the left-turn lane a 6'x 25' LOOP detector should be placed at the stopline. The head of the loop should be extended 5' ahead of the stopline.  

RECALL: ON  
MEMORY: ON.

RULE046  

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SUBJECT :: DESIGN-RULES  
DESCRIPTION :: (Movement is LAT or LATR, Major, perm & prot/perm., and <=5%.)  

If  
1) The problem to be studied is DESIGN, and  
2) The street type either major or minor is MAJOR, and  
3) speed on this approach is <=35, and  
4) 1) the movement on this approach is LAT, or  
2) the movement on this approach is LATR, and  
5) 1) The left turn movement is PERMITTED, or  
2) The left turn movement is PROTECTED/PERMITTED, and  
6) What is the left-turn % for the peak-hour volume on this approach ? is <=5%, and  
7) 1) The width of the first lane is 11, or  
2) The width of the first lane is 12, and  
8) 1) the width of the second lane is 11, or  
2) the width of the second lane is 12,  
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \( \left[ \frac{\text{The volume on this approach divided by 15}}{12} \right] \times 2.5 \), and  
2) it is definite (100%) that MAX I Green Time is \( \left[ \frac{\text{Maximum green time for the through phase in sec.; MAX I plus 20}}{12} \right] \), and  
3) it is definite (100%) that MAX II is \( \left[ \frac{\text{MAX I Green Time plus 20}}{12} \right] \), and  
4) it is definite (100%) that detector type is The recommended detector type for this approach are a PROBE detector for the through-movement lane.  

CONFIGURATION: Two PROBES are needed for this approach and should be located 110 ft. behind the stopline. Left-turning traffic is very light; therefore, it can be handled through gaps in the opposing traffic or in the yellow interval. Hence, no detector is needed.  

RECALL: ON  
MEMORY: ON.
**RULE047**

SUBJECT :: DESIGN-RULES

DESCRIPTION :: (Movement is LAT or LATR, Major, <=35, perm. & prot/perm, and >5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is LAT, or
2) the movement on this approach is LATR, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is Protected/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach? is >5%, and
7) The width of the first lane is 11, and
8) The width of the first lane is 12, and
9) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is ([The volume on this approach divided by 15] times 2.5), and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector types for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.

CONFIGURATION: Two PROBES are needed for the through lane and should be located 110 ft. behind the stopline. For the left-turn lane a 6'x20' LOOP detector should be placed 20' behind the stopline; this design is considered a second car detection.

RECALL: ON

MEMORY: ON.

**RULE048**

SUBJECT :: DESIGN-RULES

DESCRIPTION :: (Movement is LAT or LATR, Major, <=35, perm & prot/perm, <=5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is LAT, or
2) the movement on this approach is LATR, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
7) 1) the width of the first lane is 11, or
2) the width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is ([The volume on this approach divided by 15] times 2.5),
and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for
the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is. The recommended detector

type for this approach is a PROBE detector for the through-movement

lane.

CONFIGURATION: TWO PROBES are needed for the through lane and should
be located 110 ft. behind the stopline. Since left-turn lane traffic is
very light, it can be handled through the opposing traffic or the
yellow interval, therefore, no detector is needed. If you expect that a
left-turn phase will be needed or the left-turn volume will increase
substantially, a LOOP could be installed 20' behind the stopline and
should be on the OFF mode for future use.

RECALL: ON
MEMORY: ON.

RULE049
-------
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Movement is LAT & LATR, Major, <=35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) the movement on this approach is LAT, or
5) the movement on this approach is LATR, and
6) The left turn movement is PROTECTED, and
7) 1) the width of the first lane is 11, or
2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for
the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is. The recommended detector
types for this approach are a PROBE detector for the through-movement
lane and a LOOP detector for the left-turn lane.

CONFIGURATION: TWO PROBES are needed for the through lane and should
be located 110 ft. behind the stopline. For the left-turn lane a 6'x
25'loop detector should be placed at the stopline. The head of the loop
should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE050
-------
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move. is LTRR or LTR, Major, <=35, <=5%.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) a) the movement on this approach is LTTR, or
   b) the movement on this approach is LTAR, or
   c) the movement on this approach is LTT, and
5) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
6) a) The width of the first lane is 11, or
   b) The width of the first lane is 12, and
   c) The width of the second lane is 11, or
   d) The width of the second lane is 12,
Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\frac{\text{The volume on this approach divided by 15}}{2.5}]\), and
2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.; MAX I plus 20}]\), and
3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector for the through-movement lane.

**CONFIGURATION:** Two probes are needed for the through lane and should be located 110 ft. behind the stopline. For the left-turn lane, traffic is very light and can be handled through the opposing traffic or the yellow interval; therefore, no detector is needed. If you expect that a left-turn phase will be needed or the left-turn volume will increase substantially, a LOOP could be installed 20’ behind the stopline and should be on the OFF mode for future use.

**RECALL:** ON

**MEMORY:** ON.

**RULE052**

**SUBJECT:** DESIGN-RULES

**DESCRIPTION:** (Move. is TTT or TTTR or TTAR, Major, <=35.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) a) the movement on this approach is TTT, or
   b) the movement on this approach is TTTR, or
   c) the movement on this approach is TTAR, and
5) a) The width of the first lane is 11, or
   b) The width of the first lane is 12, and
   c) The width of the second lane is 11, or
   d) The width of the second lane is 12,
6) a) The width of the third lane is 11, or
   b) The width of the second lane is 12,
Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\frac{\text{The volume on this approach divided by 15}}{2.5}]\), and
2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.; MAX I plus 20}]\), and
3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

**CONFIGURATION:** Two probes are needed per lane. All probes should be
LOCATED 110 ft. back from the stop line.

RECALL: ON

MEMORY: ON.

RULE067

SUBJECT :: DESIGN-RULES

DESCRIPTION :: (Move is LTTT or LTTTR, Major, <=35, <=5%.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is LTTT, or
   2) the movement on this approach is LTTTR, and
5) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
6) 1) The width of the first lane is 11, or
    2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
    2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
    2) The width of the third lane is 12,

Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[ (\text{The volume on this approach divided by 15}) \times 2.5 \], and
2) it is definite (100%) that MAX I Green Time is \[ (\text{Maximum green time for the through phase in sec.}) \times MAX I + 20 \], and
3) it is definite (100%) that MAX II is \[ (\text{Maximum green time for the through phase in sec.}) \times MAX I + 20 \], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per the middle lane. All probes should be LOCATED 110 ft. behind the stop line. For the shared lane the left-turn traffic is light, therefore, no detection is needed.

RECALL: ON

MEMORY: ON.

RULE068

SUBJECT :: DESIGN-RULES

DESCRIPTION :: (Move is LTTT or LTTTR, Major, <=35, >5%.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is LTTT, or
   2) the movement on this approach is LTTTR, and
5) What is the left-turn % for the peak-hour volume on this approach? is >5%, and
6) 1) The width of the first lane is 11, or
    2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
    2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
2) The width of the third lane is 12.

Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15) times 2.5], and
2) it is definite (100%) that MAX I Green Time is [(Maximum green time for the through phase in sec.; MAX I plus 20)], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per the middle lane. All probes should be located 110 ft. behind the stopline. For the shared left-turn lane a 6x25' ft. loop is needed and to be installed at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE069

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move in LATT or LATTR, Major, <=35, Prot.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATT, or
2) the movement on this approach is LATTR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,

Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15) times 2.5], and
2) it is definite (100%) that MAX I Green Time is [(Maximum green time for the through phase in sec.; MAX I plus 20)], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [(The peak-hour volume on the left-turn approach divided by 15) times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per the middle lane. All probes should be located 110 ft. behind the stopline. For the protected left-turn lane a 6x20' ft. loop is needed and to be installed at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.
RULE070

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATT & LATTR, Major, <=35, Perm & Prot/Perm., >5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATT, or
2) the movement on this approach is LATTR, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTEC/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach ? is >5%, and
7) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per the middle lane. All probes should be LOCATED 110 ft. behind the stopline. For the protected left-turn lane a 6x25' ft. loop is needed and to be installed 20' behind the stopline as a second car detection.

RECALL: ON
MEMORY: ON.

RULE071

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATT or LATTR, Major, <=35, Perm & Prot/Perm, <=5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATT, or
2) the movement on this approach is LATTR, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTEC/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach ? is <=5%, and
7) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15}] \times 2.5\), and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per the middle lane. All probes should be LOCATED 110 ft. behind the stopline. For the eft-turn lane traffic is light, therefore, no detector is needed for this lane.

RECALL: ON
MEMORY: ON.

RULE072
--------
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TTTTR or TTTAR, Major, <=35.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is TTTTR, or
2) the movement on this approach is TTTAR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15}] \times 2.5\), and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per lane. All probes should be LOCATED 110 ft. back from the stopline.

RECALL: ON
MEMORY: ON.

RULE073
--------
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTR or LTTR, Major, <=35, <=5%.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LTTTTR, or
   2) the movement on this approach is LTTTAR, and
5) What is the left-turn % for the peak-hour volume on this approach? is
   <=5%, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) The width of the fourth lane is 11, or
   2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec; MAX I is [[The volume on this approach divided by 15] times 2.5],
   and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for
   the through phase in sec; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector
   type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per each lane. All probes should
be LOCATED 110 ft. behind the stopline. For the shared lane the
left-turn traffic is light, therefore, no detection is needed.

RECALL: ON.

MEMORY: ON.

RULE074

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTR or LTTTAR, Major, <=35, >5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LTTTTR, or
   2) the movement on this approach is LTTTAR, and
5) What is the left-turn % for the peak-hour volume on this approach? is
   >5%, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) The width of the fourth lane is 11, or
   2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec; MAX I is [[The volume on this approach divided by 15] times 2.5],
   and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for
   the through phase in sec; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector
   type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per each except the
shared-left-turn lane. All probes should be LOCATED 110 ft. behind the
stopline. For the shared left-turn lane a 6x20' ft. loop is needed and to be installed at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE075

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR or LATTAR, Major, <=35, Prot.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTR, or
   2) the movement on this approach is LATTAR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) The width of the fourth lane is 11, or
   2) The width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [The volume on this approach divided by 15] times 2.5, and
2) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
3) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per each of the middle lanes. All probes should be LOCATED 110 ft. behind the stopline. For the protected left-turn lane a 6x25' ft. loop is needed and to be installed at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE076

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR or LATTAR, Major, <=35, Perm & Prot/perm, >5%).

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTR, or
   2) the movement on this approach is LATTAR, and
5) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn & for the peak-hour volume on this approach is
>5%, and
7) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
10) 1) the width of the fourth lane is 11, or
    2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [([The volume on this approach divided by 15] times 2.5), and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per each of the middle lanes. All probes should be LOCATED 110 ft. behind the stopline. For the left-turn lane a 6x20' ft. loop is needed and to be installed 20' behind the stopline as a second car detection.

RECALL: ON
MEMORY: ON.

RULE077
--------
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR or LATTAR, Major, <=35, Perm & Prot/Perm, <=5%)

If 1) The problem to be studied is DESIGN, and
   2) The street type either major or minor is MAJOR, and
   3) speed on this approach is <=35, and
   4) 1) the movement on this approach is LATTTR, or
      2) the movement on this approach is LATTAR, and
   5) 1) The left turn movement is PERMITTED, or
      2) The left turn movement is PROTECTED/PERMITTED, and
   6) What is the left-turn % for the peak-hour volume on this approach ? is <=5%, and
7) 1) The width of the first lane is 11, or
    2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
10) 1) the width of the fourth lane is 11, or
    2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [([The volume on this approach divided by 15] times 2.5), and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per each of the middle lanes. All probes should be LOCATED 110 ft. behind the stopline. For the left-turn lane traffic is light, therefore, no detector is needed for this lane.

RECALL: ON
RULE078

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TR, Minor, <=35.)
If 1) The problem to be studied is DESIGN, and
   2) the street type either major or minor is MINOR, and
   3) speed on this approach is <=35, and
   4) the movement on this approach is TR, and
   5) 1) the width of through lane s is 11, or
      2) the width of through lane s is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec.; MAX I is [(The volume on this approach divided by 15] times 2.5], and
   2) it is definite (100%) that detector type is The recommended detector
type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach and should
be located at stopline. The head of loop should be extended 5' ahead of
the stopline.
RECALL: OFF
MEMORY: ON.

RULE079

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTT or LTTR, Minor, <=35.)
If 1) The problem to be studied is DESIGN, and
   2) the street type either major or minor is MINOR, and
   3) speed on this approach is <=35, and
   4) 1) the movement on this approach is LTT, or
      2) the movement on this approach is LTTR, and
   5) 1) the width of the first lane is 11, or
      2) The width of the first lane is 12, and
   6) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec.; MAX I is [(The volume on this approach divided by 15] times 2.5], and
   2) it is definite (100%) that MAX I Green Time is [Maximum green time for
   the through phase in sec.; MAX I plus 10], and
   3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
   4) it is definite (100%) that detector type is The recommended detector
type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane
and should be located at stopline. The head of loop should be extended
5' ahead of the stopline.
RECALL: OFF
MEMORY: ON.
RULE080

SUBJECT: DESIGN-RULES
DESCRIPTION: (Move is LATR, Minor, <=35, perm & prot/perm.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATR, or
2) the movement on this approach is LAT, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTED/PERMITTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
and
2) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
3) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane and should be located at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE081

SUBJECT: DESIGN-RULES
DESCRIPTION: (Move is LATR, Minor, <=35, Prot.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) the movement on this approach is LATR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
and
2) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
3) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for the through lane and should be located at the stopline. Another 6x25' loop is needed for the left-turn lane and should be located at the stopline. The head of loop should be extended 5' ahead of the stopline.
RECALL: OFF
MEMORY: ON.

RULE083

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TT or TTR or TAR, Minor, <=35.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is TT, or
2) the movement on this approach is TTR, or
3) the movement on this approach is TAR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,

Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[ \left( \text{The volume on this approach divided by 15} \right) \times 2.5 \], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x20' LOOP is needed for this approach per lane and should be located at stopline.

RECALL: OFF
MEMORY: ON.

RULE084

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TTT or TTTR or TTAR, Minor, <=35.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is TTT, or
2) the movement on this approach is TTTR, or
3) the movement on this approach is TTAR, or
4) the movement on this approach is LTTT, or
5) the movement on this approach is LTTTR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,

Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[ \left( \text{The volume on this approach divided by 15} \right) \times 2.5 \], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x20' LOOP is needed for this approach per lane and should be located at stopline.

RECALL: OFF
MEMORY: ON.

RULE085

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATT or LATTR, Minor , <=35, Prot & Perm.)
If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATT, or
2) the movement on this approach is LATTR, and
5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTED/PERMITTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,
Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is ([The volume on this approach divided by 15] times 2.5), and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane and should be located 20' behind the stopline, as a second car detection.

RECALL: OFF
MEMORY: ON.

RULE086

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATT or LATTR, Minor, <=35, Prot.)
If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATT, or
2) the movement on this approach is LATTR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,

Then 1) it is definite (100%) that maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for each of the through lanes and should be located at the stop line. For the left-turn lane a 6x25' LOOP is needed and should be placed at the stop line. The head of loop should be extended 5' ahead of the stop line.

RECALL: OFF
MEMORY: ON.

RULE087

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is T or TR, Major or Minor, >35.)
If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) Speed on this approach is >35, and
4) 1) The movement on this approach is T, or
2) The movement on this approach is TR, and
5) 1) The width of through lane s is 11, or
2) The width of through lane s is 12,

Then 1) it is definite (100%) that maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach. The exact locations of the probes are given next.

RECALL: ON
MEMORY: ON.

RULE088

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Speed is 40 Dilemma zone.)
If 1) Speed on this approach is >35, and
2) The speed of the high speed approach is 40,

Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is The passage time setting is
2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 220 ft. behind the near probes.
The EXTENSION time for the far probes: 2.3 sec.

RULE089
SUBJECT: DESIGN-RULES
DESCRIPTION: (Speed is 45 Dilema zone.)
If 1) speed on this approach is >35, and
2) The speed of the high speed approach is 45,
Then it is definite (100%) that the PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is The passage Time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 256 ft. behind the near probes.
The EXTENSION time for the far probes: 2.4 sec.

RULE090
SUBJECT: DESIGN-RULES
DESCRIPTION: (Speed is 50 Dilema zone.)
If 1) speed on this approach is >35, and
2) The speed of the high speed approach is 50,
Then it is definite (100%) that the PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is The passage Time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 293 ft. behind the near probes.
The EXTENSION time for the far probes: 2.5 sec.

RULE091
SUBJECT: DESIGN-RULES
DESCRIPTION: (Speed is 55 Dilema zone.)
If 1) speed on this approach is >35, and
2) The speed of the high speed approach is 55,
Then it is definite (100%) that the PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is The passage Time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 330 ft. behind the near probes.
The EXTENSION time for the far probes: 2.5 sec.

RULE092
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Speed is 60 Dilema zone.)

If  1) speed on this approach is >35, and
   2) The speed of the high speed approach is 60,
Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is The passage Time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.

The FAR PROBES should be located 367 ft. behind the near probes.

The EXTENSION time for the far probes : 2.6 sec.

RULE093

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Speed is 65 Dilema zone.)

If  1) speed on this approach is >35, and
   2) The speed of the high speed approach is 65,
Then it is definite (100%) that The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is The passage Time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.

The FAR PROBES should be located 404 ft. behind the near probes.

The EXTENSION time for the far probes : 2.6 sec.

RULE095

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TT or TTR, Maj. & Min., >35.)

If  1) The problem to be studied is DESIGN, and
   2)  1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
   3) speed on this approach is >35, and
   4)  1) the movement on this approach is TT, or
       2) the movement on this approach is TTR, or
       3) the movement on this approach is TAR, or
       4) the movement on this approach is LTR, or
       5) the movement on this approach is LTT, or
       6) the movement on this approach is LTAR, and
       5) 1) The width of the first lane is 11, or
           2) The width of the first lane is 12, and
       6) 1) the width of the second lane is 11, or
           2) the width of the second lane is 12,
Then  1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15) times 2.5], and
   2) it is definite (100%) that MAX I Green Time is (Maximum green time for the through phase in sec.; MAX I plus 20), and
   3) it is definite (100%) that MAX II is (MAX I Green Time plus 20), and
   4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.
CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE097

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LAT or LATR, Maj. & Min., >35, Per & Prot/Perm, <=5%)

If 1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
   3) speed on this approach is >35, and
   4) 1) the movement on this approach is LAT, or
      2) the movement on this approach is LATR, and
   5) 1) The left turn movement is PERMITTED, or
      2) The left turn movement is PROTECTED/PERMITTED, and
   6) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
   7) 1) The width of the first lane is 11, or
      2) The width of the first lane is 12, and
   8) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \(\left[\frac{\text{The volume on this approach divided by 15}}{2.5}\right]\), and

2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and

3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and

4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE098

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LAT or LATR, Maj. & Min., >35, Per & Prot/Perm, >5%)

If 1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
   3) speed on this approach is >35, and
   4) 1) the movement on this approach is LAT, or
      2) the movement on this approach is LATR, and
   5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach? is >5%, and
7) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x25' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located 20' behind the stopline, as a second car detection.

RECALL: ON
MEMORY: OFF.

RULE099

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LAT or LATR, Maj. $ Min., >35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LAT, or
2) the movement on this approach is LATR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [(The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x25' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located at the stopline. The front of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: OF.

RULE 100

-----
SUBJECT: DESIGN-RULES
DESCRIPTION: (Move is LATT or LATTR, Maj. $ Min., >35, Perm & Prot/Perm, >5%.)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
   2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LATT, or
   2) the movement on this approach is LATTR, and
5) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach? is >5%, and
7) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high-speed approach; therefore, the dilemma zone technique should be implemented. Two NEAR probes and two FAR probes are needed for this approach per lane. The exact locations of these probes will be detailed shortly. In addition, a 6' x 25' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located 20' behind the stopline.

RECALL: ON
MEMORY: OF.

RULE 101

-----
SUBJECT: DESIGN-RULES
DESCRIPTION: (Move is LATT or LATTR, Maj. $ Min., >35, Perm & Prot/Perm, <=5%.)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
   2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) the movement on this approach is LATT, and
5) the movement on this approach is LATTR, and
6) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
7) What is the left-turn % for the peak-hour volume on this approach? is
RULE102

SUBJECT : DESIGN-RULES

DESCRIPTION : (Move is LATT or LATTR, Maj. $ Min., > 35, Prot.)

If 1) The problem to be studied is DESIGN, and
  2) 1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
  3) speed on this approach is > 35, and
  4) 1) the movement on this approach is LATT, or
      2) the movement on this approach is LATTR, and
  5) The left turn movement is PROTECTED, and
  6) 1) The width of the first lane is 11, or
      2) The width of the first lane is 12, and
  7) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12, and
  8) 1) The width of the third lane is 11, or
      2) The width of the third lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
  sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
  2) it is definite (100%) that MAX I Green Time is [Maximum green time for
      the through phase in sec.; MAX I plus 20], and
  3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
  4) it is definite (100%) that detector type is The recommended detector
      type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach; therefore, the dilemma
zone technique should be implemented. Two NEAR probes and two FAR
probes are needed for this approach for each lane. The exact locations
of probes will be detailed shortly.

RECALL: ON

MEMORY: OF.
front of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: OF.

RULE103

SUBJECT : DESIGN-RULES
DESCRIPTION : (Move is LLT or LLTR, Maj. $ Min., >35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) The street type either major or minor is MINOR, and
4) Speed on this approach is >35, and
5) 1) the movement on this approach is LLT, or
   2) the movement on this approach is LLTR, and
6) The left turn movement is PROTECTED, and
7) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
8) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX $ is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
3) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach per each lane. The exact locations of probes are given next. A 6x20' LOOP is needed also for each of the left-turn lanes to handle the left-turn traffic and should be located at the stopline. The front of loop should be extended ahead of the stopline.

RECALL: ON
MEMORY: OF.

RULE104

SUBJECT : DESIGN-RULES
DESCRIPTION : (Move is TT or TTR or TAR, Major, <=35.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) Speed on this approach is <=35, and
4) 1) the movement on this approach is TT, or
   2) the movement on this approach is TTR, or
   3) the movement on this approach is TAR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two PROBES are needed per lane for this approach and should be located 110 ft. behind the stopline.

RECALL: ON
MEMORY: ON.

RULE111

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TTTTTR or TTTTAR, Major, <=35.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is TTTTTR, or
   2) the movement on this approach is TTTTAR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
8) 1) The width of the fourth lane is 11, or
   2) The width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
   2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two PROBES are needed for lane. All probes should be located 110 ft. behind the stopline.

RECALL: ON
MEMORY: ON.

RULE112

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTR, Maj., <=35, <=5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LTTTTTR, or
   2) the movement on this approach is LTTTTAR, and
5) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
   2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12, and
10) 1) The width of the fifth lane is 11, or
    2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per each lane. All probes should be located 110 ft. behind the stopline. For the shared lane the left-turn traffic is light, therefore, no detection is provided.

RECALL: ON

MEMORY: ON.

RULE113

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTTR, Maj., <=35, >5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <35, and
4) 1) the movement on this approach is LTTTTTR, or
   2) the movement on this approach is LTTTTAR, and
5) What is the left-turn % for the peak-hour volume on this approach? is >5%, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
   2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12, and
10) 1) The width of the fifth lane is 11, or
     2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type.
type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the each except the shared-left-turn lane. All probes should be LOCATED 110 ft. behind the stopline. For the shared left-turn lane a 6x25' ft. loop is needed and to be installed at stopline. The front of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE114

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR $ LATTTR, Maj,<=35,Prot.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTR, or
2) the movement on this approach is LATTTR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
9) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12, and
10) 1) The width of the fifth lane is 11, or
2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed for the curb lane and two probes for each of the middle lanes. All probes should be LOCATED 110 ft. behind the stopline. For the protected left-turn lane a 6x20' ft. loop is needed and to be installed at the stopline. The front of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE115

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTTR $ LTTTTAR, Maj,<=35,Perm & Prot/perm,
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTTR, or
   2) the movement on this approach is LATTTAR, and
5) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach ? is >5%, and
   7) 1) The width of the first lane is 11, or
      2) The width of the first lane is 12, and
   8) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12, and
   9) 1) The width of the third lane is 11, or
      2) The width of the third lane is 12, and
  10) 1) the width of the fourth lane is 11, or
      2) the width of the fourth lane is 12, and
  11) 1) The width of the fifth lane is 11, or
      2) The width of the fifth lane is 12.

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed for the curb lane and two probes for each of the middle lanes. All probes should be LOCATED 110 ft. behind the stopline. For the protected left-turn lane a 6x25' ft. loop is needed and to be installed 20' behind the stopline, as a second car detection.

RECALL: ON
MEMORY: ON.

RULE116

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTTR $ LATTTAR,Maj,<=35,Perm $ Prot/Perm, <=5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTTR, or
   2) the movement on this approach is LATTTAR, and
5) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach ? is <=5%, and
   7) 1) The width of the first lane is 11, or
      2) The width of the first lane is 12, and
   8) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12, and
   9) 1) The width of the third lane is 11, or
      2) The width of the third lane is 12, and
10) 1) the width of the fourth lane is 11, or  
   2) the width of the fourth lane is 12, and  

11) 1) The width of the fifth lane is 11, or  
   2) The width of the fifth lane is 12,  

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by } 15\text{]} \times 2.5\), and 

2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.}; \text{MAX I plus 20}]\), and 

3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and 

4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector. 

CONFIGURATION: Two probes are needed for the curb lane and two probes for each of the middle lanes. All probes should be LOCATED 110 ft. behind the stopline. For the left-turn lane traffic is light, therefore, no detector is needed for this lane. 

RECALL: ON 

MEMORY: ON. 

RULE117 

SUBJECT :: DESIGN-RULES 

DESCRIPTION :: (Move is TTTTR & TTTAR, Minor, <=35.) 

If 1) The problem to be studied is DESIGN, and  
2) The street type either major or minor is MINOR, and  
3) speed on this approach is <=35, and  
4) 1) the movement on this approach is TTTTR, or  
   2) the movement on this approach is TTTAR, and  
5) 1) The width of the first lane is 11, or  
   2) The width of the first lane is 12, and  
6) 1) the width of the second lane is 11, or  
   2) the width of the second lane is 12, and  
7) 1) The width of the third lane is 11, or  
   2) The width of the second lane is 12, and  
8) 1) the width of the fourth lane is 11, or  
   2) the width of the fourth lane is 12,  

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by } 15\text{]} \times 2.5\), and 

2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.}; \text{MAX I plus 10}]\), and 

3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and 

4) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector. 

CONFIGURATION: A 6x20' LOOP is needed for this approach for each lane and should be located at stopline. 

RECALL: OFF 

MEMORY: ON. 

RULE118 

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTR, Minor, <=35, <=5%.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) the movement on this approach is LTTTTR, and
5) the movement on this approach is LTTTAR, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
2) The width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
9) 1) The width of the fourth lane is 11, or
2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x20' LOOP is needed for this approach for each lane and should be located at stopline.

RECALL: OFF
MEMORY: ON.

RULE119

SUBJECT :: DESIGN-RULES

DESCRIPTION :: (Move is TTTTR $$ TTTAR, Maj $$ Min, >35.)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is TTTTR, or
2) the movement on this approach is TTTAR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) The width of the second lane is 11, or
2) The width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) The width of the fourth lane is 11, or
2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes
are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE120

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTR \& LTTTAR, Maj \& Min, >35, <=5%.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, or
3) The street type either major or minor is MINOR, and
4) speed on this approach is >35, and
5) 1) the movement on this approach is LTTTTR, or
2) the movement on this approach is LTTTAR, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
2) The width of the second lane is 12, and
8) 1) The width of the fourth lane is 11, or
2) The width of the fourth lane is 12,

Then
1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE121

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTR \& LTTTAR, Min,<=35, >5%.)

If
1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LTTTTR, or
2) the movement on this approach is LTTTAR, and
5) What is the left-turn % for the peak-hour volume on this approach ? is >5%, and
6) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
2) The width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
    2) The width of the third lane is 12, and
9) 1) the width of the fourth lane is 11, or
    2) the width of the fourth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15} \times 2.5]\), and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25’ LOOP is needed for this approach for each lane and should be located at stopline. The front of the loop should be extended 5’ ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE122

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTT or LTTTR, Maj $ Min, >35.)
If 1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
       2) The street type either major or minor is MINOR, and
   3) speed on this approach is >35, and
   4) 1) the movement on this approach is LTTTT, or
       2) the movement on this approach is LTTTR, and
   5) 1) the width of the first lane is 11, or
       2) The width of the first lane is 12, and
   6) 1) the width of the second lane is 11, or
       2) the width of the second lane is 12, and
   7) 1) The width of the third lane is 11, or
       2) The width of the third lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15} \times 2.5]\), and
2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.}; \text{MAX I plus 20}]\), and
3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OFF.

RULE123

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR $ LATTAR, Maj $ Min, >35, Prot.)
If 1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LATTTR, or
   2) the movement on this approach is LATTAR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) The width of the fourth lane is 11, or
   2) the width of the first lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that Maximum green time for the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x20’ LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located at the stopline. The front of the loop should be extended 5’ ahead of the stopline.

RECALL: ON
MEMORY: OF.

RULE124
SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR $ LATTAR, Min, <=35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTR, or
   2) the movement on this approach is LATTAR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by
15) times 2.5], and
   3) it is definite (100%) that detector type is The recommended detector
type for this approach is a LOOP detector.

   CONFIGURATION: A 6x25' LOOP is needed for each of the through and
   should be located at the stopline. For the left-turn lane a 6x25' LOOP
   is needed and should be located at the stopline. The front of the loop
   should be extended 5' ahead of the stopline.

   RECALL: OFF
   MEMORY: ON.

RULE125

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR $ LATTAR, Min, <=35, Perm $ Prot/Perm.)
If 1) The problem to be studied is DESIGN, and
   2) The street type either major or minor is MINOR, and
   3) speed on this approach is <=35, and
   4) 1) the movement on this approach is LATTTR, or
      2) the movement on this approach is LATTAR, and
   5) 1) The left turn movement is PERMITTED, or
      2) The left turn movement is PROTECTED/PERMITTED, and
   6) 1) The width of the first lane is 11, or
      2) The width of the first lane is 12, and
   7) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12, and
   8) 1) The width of the third lane is 11, or
      2) The width of the third lane is 12, and
   9) 1) The width of the fourth lane is 11, or
      2) the width of the fourth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec.; MAX I is [[(The volume on this approach divided by 15] times 2.5],
and
   2) it is definite (100%) that detector type is The recommended detector
   type for this approach is a LOOP detector.

   CONFIGURATION: A 6x25' LOOP is needed for this approach for lane
   and should be located at stopline. The front of the loop should
   be extended 5' ahead of the stopline.

   RECALL: OFF
   MEMORY: ON.

RULE126

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTR $ LATTAR, Maj $ Min, >35, Perm $ Prot/Perm, >5%.)
If 1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
   3) speed on this approach is >35, and
   4) 1) the movement on this approach is LATTTR, or
      2) the movement on this approach is LATTAR, and
   5) 1) The left turn movement is PERMITTED, or
2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach ? is
>5%, and
7) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
   2) the width of the third lane is 12, and
10) 1) the width of the fourth lane is 11, or
    2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that detector type is The recommended detector
type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the
dilemma-zone technique is applied. Two NEAR probes and two FAR probes
are needed for this approach for each lane. The exact locations of
probes are given next. A 6x20' LOOP is needed for the left-turn lane to
handle the left-turn traffic and should be located 20' behind the
stopline.

RECALL: ON

MEMORY: OF.

RULE127

SUBJECT:: DESIGN-RULES
DESCRIPTION:: (Move is LATTTR $ LATTAR, Maj $ Min, >35, Perm $ Prot/Perm, <=5%.)
If 1) The problem to be studied is DESIGN, and
  2) 1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
  3) speed on this approach is >35, and
  4) 1) the movement on this approach is LATTTR, or
      2) the movement on this approach is LATTAR, and
  5) 1) The left turn movement is PERMITTED, or
      2) The left turn movement is PROTECTEC/PERMITTED, and
  6) What is the left-turn % for the peak-hour volume on this approach ? is
     <=5%, and
  7) 1) The width of the first lane is 11, or
      2) The width of the first lane is 12, and
  8) 1) the width of the second lane is 11, or
      2) the width of the second lane is 12, and
  9) 1) The width of the third lane is 11, or
      2) the width of the third lane is 12, and
 10) 1) the width of the fourth lane is 11, or
     2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that detector type is The recommended detector
type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the
dilemma-zone technique is applied. Two NEAR probes and two FAR probes
are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE130

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Minimum Green Time)
If The street type either major or minor is MINOR,
Then it is definite (100%) that The Minimum Green Time Setting is 10 sec..

RULE131

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Minimum Green Time)
If The street type either major or minor is MAJOR,
Then it is definite (100%) that The Minimum Green Time Setting is 20 sec..

RULE132

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Green and Min. Green for Left Turn Movement)
If 1) 1) the movement on this approach is LATR, or
2) the movement on this approach is LATTAR, or
3) the movement on this approach is LATTTR, or
4) the movement on this approach is LATT, or
5) the movement on this approach is LATTTR, or
6) the movement on this approach is LATTAR, and
2) The street type either major or minor is MAJOR, and
1) The left turn movement is PROTECTED, or
2) The left turn movement is PROTECTED/PERMITTED,
Then 1) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
2) it is definite (100%) that The Minimum Green Time Setting is For the through phase, 20 secs.; for the left-turn phase, 10 secs. Detector Delay Time is 8 secs.

RULE146

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is T or TR, Maj $ Min, >35.)
If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is T, or
2) the movement on this approach is TR, or
3) the movement on this approach is TL, or
4) the movement on this approach is LTR, and
5) 1) the width of through lane s is 12, or
2) the width of through lane s is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in
sec.; MAX I is \([\text{The volume on this approach divided by 15} \text{ times 2.5}]\), and

2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.} \text{; MAX I plus 15}]\), and

3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 15}]\), and

4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach. The exact locations of probes are given next.

RECALL: ON

MEMORY: OFF.

RULE148

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is T or TL or LTR, Maj $ Min, >35)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is T, or
2) the movement on this approach is TL, or
3) the movement on this approach is LTR, and
5) 1) the width of through lane s is 11, or
2) the width of through lane s is 12,

Then it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15}]\).

RULE150

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TTT $ TTTR $ TTAR, Maj $ Min, >35.)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is TTT, or
2) the movement on this approach is TTTR, or
3) the movement on this approach is TTAR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15} \text{ times 2.5}]\), and

2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for the through phase in sec.} \text{; MAX I plus 20}]\), and

3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and

4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.
CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE151

**SUBJECT:** DESIGN-RULES
**DESCRIPTION:** (Move is LTTT $ LTTTR, Min, <=35.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) The movement on this approach is LTTT, or
   2) The movement on this approach is LTTTR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12,

Then it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[\frac{\text{The volume on this approach divided by 15}}{2.5}\].

RULE152

**SUBJECT:** DESIGN-RULES
**DESCRIPTION:** (Move is LLT $ LLTR, Maj, >=35, Prot.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is >=35, and
4) 1) The movement on this approach is LLT, or
   2) The movement on this approach is LLTR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, or
   3) The width of the third lane is 11, or
   4) The width of the third lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[\left(\text{The volume on this approach divided by 15} \times 2.5\right)\], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \[\left(\text{The peak-hour volume on the left-turn approach divided by 15} \times 2.5\right)\], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector for the through movement lane and a LOOP detector for left-turn lanes.

CONFIGURATION: TWO PROBES are needed for the through lane and should be located 110 ft. behind the stopline. For each left-turn lane a
6x25'loop detector should be placed at the stopline. The front of loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE153

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TTTTTR $ TTTTAR, Min, <=35.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is TTTTTR, or
   2) the movement on this approach is TTTTAR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the second lane is 12, and
8) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
   2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach for each lane and should be located at stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE154

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is TTTTTR $ TTTTAR, Maj & Min, >35.)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
   2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is TTTTTR, or
   2) the movement on this approach is TTTTAR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
265

2) the width of the second lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
2) The width of the fifth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE157

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTTR, Maj $ Min, >35, <=5%.)
If
1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LTTTTTR, or
2) the movement on this approach is LTTTTAR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
2) The width of the fifth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: OF.

RULE158

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTTR, Min, <=35, Prot.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LATTTTR, or
   2) the movement on this approach is LATTTAR, and
5) The left turn movement is PROTECTED, and
6) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
7) 1) The width of the second lane is 11, or
   2) The width of the second lane is 12, and
8) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
9) 1) The width of the fourth lane is 11, or
   2) The width of the fourth lane is 12, and
10) 1) The width of the fifth lane is 11, or
    2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for each of the through and should be located at the the stopline. For the left-turn lane a 6x25' LOOP is needed and should be located at the stopline too. The head of the loop should be extended 5' ahead of the stopline.

RECALL: OFF

MEMORY: ON.

RULE159

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LATTTTR, Min, >35, Perm & Prot/Perm, >5%.)

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
   2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LATTTTR, or
   2) the movement on this approach is LATTTAR, and
5) 1) The left turn movement is PERMITTED, or
   2) The left turn movement is PROTECTED/PERMITTED, and
6) What is the left-turn % for the peak-hour volume on this approach is >5%, and
7) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
8) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
10) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12, and
11) 1) The width of the fifth lane is 11, or
2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
sec.; MAX I is \[\left(\text{The volume on this approach divided by 15}\right) \times 2.5\], and
2) it is definite (100%) that MAX I Green Time is \[\left(\text{Maximum green time for the}
\text{through phase in sec.; MAX I plus 20}\right)\], and
3) it is definite (100%) that MAX II is \[\left(\text{MAX I Green Time plus 20}\right)\], and
4) it is definite (100%) that detector type is \(T\)he recommended detector type
for this approach is a \textit{PROBE} detector.

CONFIGURATION: This is a high speed approach, therefore, the
dilema-zone technique is applied. Two \textit{NEAR} probes and two \textit{FAR} probes
are needed for this approach for each lane. The exact locations of
probes are given next. A \textit{6x20'} \textit{LOOP} is needed for the left-turn lane to
handle the left-turn traffic and should be located \textit{20'} behind the
stopline as a second car detection.

RECALL: \textit{ON}

MEMORY: OF.
CONFIGURATION: A 6x25' LOOP is needed for this approach for each lane and should be located at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE161
Subject: DESIGN-RULES
Description: (Move is LATTTTR, Maj $ Min, >35, Perm & Prot/Perm, <=5%.)

If 1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
      2) The street type either major or minor is MINOR, and
   3) speed on this approach is >35, and
   4) 1) the movement on this approach is LATTTTR, or
      2) the movement on this approach is LATTTR, and
   5) 1) The left turn movement is PERMITTED, or
      2) The left turn movement is PROTECTED/PERMITTED, and
   6) What is the left-turn % for the peak-hour volume on this approach? is <=5%, and
    7) 1) The width of the first lane is 11, or
       2) The width of the first lane is 12, and
    8) 1) the width of the second lane is 11, or
       2) the width of the second lane is 12, and
    9) 1) The width of the third lane is 11, or
       2) The width of the third lane is 12, and
   10) 1) the width of the fourth lane is 11, or
       2) the width of the fourth lane is 12, and
   11) 1) The width of the fifth lane is 11, or
       2) The width of the fifth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
   2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
   3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
   4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: ON.

RULE163
Subject: DESIGN-RULES
Description: (Move is LTTTTR, Min, <=35, >5%.)

If 1) The problem to be studied is DESIGN, and
   2) The street type either major or minor is MINOR, and
   3) speed on this approach is <=35, and
4) 1) the movement on this approach is LTTTTTR, or
   2) the movement on this approach is LTTTTAR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
   2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
   and
   2) it is definite (100%) that MAX I Green Time is [Maximum green time for
      the through phase in sec.; MAX I plus 10], and
   3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
   4) it is definite (100%) that detector type is The recommended detector
type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach for each
lane and should be located at the stopline. The front of the loop
should be extended 5' ahead of the loop.

RECALL: OFF

MEMORY: ON.

RULE165

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTTR, Maj $ Min, >35.)
If
   1) The problem to be studied is DESIGN, and
   2) 1) The street type either major or minor is MAJOR, or
       2) The street type either major or minor is MINOR, and
       3) speed on this approach is >35, and
   4) 1) the movement on this approach is LTTTTTR, or
       2) the movement on this approach is LTTTTAR, and
       5) 1) The width of the first lane is 11, or
           2) The width of the first lane is 12, and
           6) 1) the width of the second lane is 11, or
               2) the width of the second lane is 12, and
               7) 1) The width of the third lane is 11, or
                   2) The width of the third lane is 12, and
                   8) 1) the width of the fourth lane is 11, or
                       2) the width of the fourth lane is 12, and
                       9) 1) The width of the fifth lane is 11, or
                           2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in
   sec.; MAX I is [[The volume on this approach divided by 15] times 2.5],
   and
   2) it is definite (100%) that MAX I Green Time is [Maximum green time for
      the through phase in sec.; MAX I plus 20], and
   3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
   4) it is definite (100%) that detector type is The recommended detector
type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the
dilema-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON
MEMORY: ON.

RULE167
SUBJECT:: DESIGN-RULES
DESCRIPTION:: (Move is LLTTTTR, Maj, <=35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) the movement on this approach is LLTTTTR, and
5) 1) The width of the first lane is 11, or
  2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
  2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
  2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
  2) the width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
  2) The width of the fifth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[
\left(\frac{\text{volume on this approach}}{15}\right) \times 2.5,
\]
and
2) it is definite (100%) that MAX I Green Time is \(\text{Maximum green time for the through phase in sec.} + 20\), and
3) it is definite (100%) that MAX II is \(\text{MAX I Green Time} + 20\), and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \(\text{MAX I Green Time} + 20\), and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector for the through-movement lane and a LOOP detector for left-turn lanes.

CONFIGURATION: TWO PROBES are needed for each of the through lanes and should be located 110 ft. behind the stopline. For each left-turn lane a 6x25' loop detector should be placed at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE168
SUBJECT:: DESIGN-RULES
DESCRIPTION:: (Move is LLTTTTR, Maj $ Min, >35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
  2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) the movement on this approach is LLTTTTR, and
5) 1) The width of the first lane is 11, or
271

2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) The width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x25' LOOP is needed also for each of the left-turn lanes to handle the left-turn traffic and should be located at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: ON

MEMORY: OF.

RULE180

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LLTT $ LLTTR, Min, <=35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LLTT, or
2) the movement on this approach is LLTTR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) The width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) The width of the fourth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 10], and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [[The peak-hour volume on the left-turn approach divided by 15] times 2.5], and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for each lane for this approach and should be located at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE181

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LLTT & LLTTR, Maj & Min, >35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LLTT, or
2) the movement on this approach is LLTTR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \(\left[\frac{\text{The volume on this approach divided by 15}}{2.5}\right]\), and
2) it is definite (100%) that MAX I Green Time is \(\left[\text{MAX I Green Time plus 20}\right]\), and
3) it is definite (100%) that MAX II is \(\left[\text{MAX I Green Time plus 20}\right]\), and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \(\left[\frac{\text{The peak-hour volume on the left-turn approach divided by 15}}{2.5}\right]\), and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x25' LOOP is needed also for each of the left-turn lanes to handle the left-turn traffic and should be located at the stopline.

RECALL: ON
MEMORY: OF.

RULE182

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LLTT & LLTTR, Maj, <=35, Prot.)
If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LLTT, or
2) the movement on this approach is LLTTR, and
5) 1) The width of the first lane is 11, or
2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
2) the width of the fourth lane is 12,
Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \( \left[ \frac{\text{The volume on this approach}}{15} \times 2.5 \right] \), and
2) it is definite (100%) that MAX I Green Time is \( \left[ \text{Maximum green time for the through phase in sec.; MAX I plus 20} \right] \), and
3) it is definite (100%) that MAX II is \( \left[ \text{MAX I Green Time plus 20} \right] \), and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \( \left[ \frac{\text{The peak-hour volume on the left-turn approach}}{15} \times 2.5 \right] \), and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector for the through movement and a LOOP detector for each of left-turn lanes.

CONFIGURATION: TWO PROBES are needed for each through lane and should be located 110 ft. behind the stopline. For each left-turn lane a 6x25' loop detector should be placed at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.
be LOCATED 110 ft. behind the stopline. For the shared left-turn lane a 6x25' ft. loop is needed and to be installed at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: ON.

RULE188

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is T $ TR, Major, <=35.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MAJOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is T, or
   2) the movement on this approach is TR, and
5) 1) the width of through lane s is 11, or
   2) the width of through lane s is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and
3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and
4) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: TWO PROBES are needed for this approach and should be located 110 ft. behind the stopline.

RECALL: ON
MEMORY: ON.

RULE190

SUBJECT :: DESIGN-RULES
DESCRIPTION :: (Move is LTTTTR $ LTTTAR, Min, <=35.)

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is <=35, and
4) 1) the movement on this approach is LTTTTR, or
   2) the movement on this approach is LTTTAR, and
5) 1) The width of the first lane is 11, or
   2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [[The volume on this approach divided by 15] times 2.5], and
2) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.
CONFIGURATION: A 6x25' LOOP is needed for this approach for each lane and should be located at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE195

SUBJECT :: DESIGN-RULES
If 1) the movement on this approach is LATR, or
   2) the movement on this approach is LATTR, or
   3) the movement on this approach is LATT, or
   4) the movement on this approach is LATTTR, or
   5) the movement on this approach is LATTAR, or
   6) the movement on this approach is LATTTTR, or
   7) the movement on this approach is LATTTAR, and
   2) The left turn movement is PERMITTED,
Then it is definite (100%) that Maximum green time of the left-turn phase in sec. is No need for a left-turn phase in this case.

RULE196

SUBJECT :: DESIGN-RULES
If 1) the movement on this approach is T, or
   2) the movement on this approach is TL, or
   3) the movement on this approach is LTR, or
   4) the movement on this approach is TT, or
   5) the movement on this approach is LTR, or
   6) the movement on this approach is LTAR, or
   7) the movement on this approach is LTTR, or
   8) the movement on this approach is TTTR, or
   9) the movement on this approach is TTR, or
  10) the movement on this approach is LTT, or
  11) the movement on this approach is TTTR, or
  12) the movement on this approach is LTTT, or
  13) the movement on this approach is TTT, or
  14) the movement on this approach is LTTTR, or
  15) the movement on this approach is TTTTR, or
  16) the movement on this approach is LTTT, or
  17) the movement on this approach is LTTTTTR, or
Then it is definite (100%) that Maximum green time of the left-turn phase in sec. is No left-turn phase in this case.

RULE197

SUBJECT :: DESIGN-RULES
If 1) the movement on this approach is LATR, or
   2) the movement on this approach is LATTR, or
   3) the movement on this approach is LATTTR, or
   4) the movement on this approach is LATTAR, or
   5) the movement on this approach is LATTTTR, or
   6) the movement on this approach is LATTTAR, and
   2) The street type either major or minor is MINOR, and
   3) 1) The left turn movement is PROTECTED, or
   2) The left turn movement is PROTECTED/PERMITTED,
Then 1) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \([\text{The peak-hour volume on the left-turn approach divided by 15}] \times 2.5\), and 2) it is definite (100%) that The Minimum Green Time Setting is 10 sec., For the through phase is 10 sec., For the left-turn phase is 10 sec., and Detector Delay Time is 8 seconds.

RULE198

SUBJECT :: DESIGN-RULES

If 1) The problem to be studied is DESIGN, and 2) The street type either major or minor is MINOR, and 3) speed on this approach is <35, and 4) 1) the movement on this approach is LAT, or 2) the movement on this approach is LATR, and 5) The left turn movement is PROTECTED, and 6) 1) The width of the first lane is 11, or 2) The width of the first lane is 12, and 7) 1) the width of the second lane is 11, or 2) the width of the second lane is 12, Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \([\text{The volume on this approach divided by 15}] \times 2.5\), and 2) it is definite (100%) that MAX I Green Time is \([\text{MAX I Green Time plus 10}]\), and 3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and 4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \([\text{The peak-hour volume on the left-turn approach divided by 15}] \times 2.5\), and 5) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for the through lane and should be located at the stopline. For the left-turn lane a 6x25' LOOP is needed and should be placed at the stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE199

SUBJECT :: DESIGN-RULES

If 1) The problem to be studied is DESIGN, and 2) 1) The street type either major or minor is MAJOR, or 2) The street type either major or minor is MINOR, and 3) speed on this approach is >35, and 4) 1) the movement on this approach is LATT, or 2) the movement on this approach is LATTR, and 5) 1) The left turn movement is PERMITTED, or 2) The left turn movement is PROTECTED/PERMITTED, and 6) What is the left-turn % for the peak-hour volume on this approach ? is <5%, and 7) 1) The width of the first lane is 11, or 2) The width of the first lane is 12, and 8) 1) the width of the second lane is 11, or 2) the width of the second lane is 12, and
9) 1) The width of the third lane is 11, or
2) The width of the third lane is 12.
   Then 1) it is definite (100%) that maximum green time for the through phase in
   sec.; MAX I is \([\text{The volume on this approach divided by } 15] \times 2.5\), and
2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for}
   
   the through phase in sec.}; \text{MAX I plus 20}]\), and
3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and
4) it is definite (100%) that detector type is the recommended detector
   type for this approach is a PROBE detector.

   CONFIGURATION: This is a high speed approach, therefore, the
   dilemma-zone technique is applied. Two NEAR probes and two FAR probes
   are needed for this approach for each lane. The exact locations of
   probes are given next.

   RECALL: ON
   MEMORY: OF.

RULE200

SUBJECT: DESIGN-RULES

If 1) The problem to be studied is DESIGN, and
2) 1) The street type either major or minor is MAJOR, or
   2) The street type either major or minor is MINOR, and
3) speed on this approach is >35, and
4) 1) the movement on this approach is LLT, or
   2) the movement on this approach is LLTR, and
5) 1) The width of the first lane is 11, or
   2) the width of the first lane is 12, and
6) 1) The width of the second lane is 11, or
   2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12.

   Then 1) it is definite (100%) that maximum green time for the through phase in
   sec.; MAX I is \([\text{The volume on this approach divided by } 15] \times 2.5\), and
2) it is definite (100%) that MAX I Green Time is \([\text{Maximum green time for}
   
   the through phase in sec.}; \text{MAX I plus 20}]\), and
3) it is definite (100%) that MAX II is \([\text{MAX I Green Time plus 20}]\), and
4) it is definite (100%) that maximum green time of the left-turn phase
   in sec. is \([\text{The peak-hour volume on the left-turn approach divided by}
   
   15] \times 2.5\), and
5) it is definite (100%) that detector type is the recommended detector
   type for this approach is a PROBE detector.

   CONFIGURATION: This is a high speed approach, therefore, the
   dilemma-zone technique is applied. Two NEAR probes and two FAR probes
   are needed for this approach for each lane. The exact locations of
   probes are given next. A 6x25' LOOP is needed for each left-turn lane
   to handle the left-turn traffic and should be located at the stopline.
   The front of loop should be extended 5' ahead of the stopline.

   RECALL: ON
   MEMORY: OF.
RULE201

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**SUBJECT:** DESIGN-RULES

If 1) the movement on this approach is LLTR, or 2) the movement on this approach is LLT, or 3) the movement on this approach is LLTR, or 4) the movement on this approach is LLTT, or 5) the movement on this approach is LLTTTR, or 6) the movement on this approach is LLTTT, and 2) the street type either major or minor is MAJOR,

Then 1) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \[\frac{\text{peak-hour volume on the left-turn approach divided by 15}}{2.5}\], and 2) it is definite (100%) that The Minimum Green Time Setting is For the through phase, 20 secs.; for the left-turn phase, 10 secs. Detector Delay Time is 8 secs.

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RULE202

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**SUBJECT:** DESIGN-RULES

If 1) the movement on this approach is LLTR, or 2) the movement on this approach is LLT, or 3) the movement on this approach is LLTR, or 4) the movement on this approach is LLTT, or 5) the movement on this approach is LLTTTR, or 6) the movement on this approach is LLTTT, and 2) The street type either major or minor is MINOR,

Then 1) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \[\frac{\text{peak-hour volume on the left-turn approach divided by 15}}{2.5}\], and 2) it is definite (100%) that The Minimum Green Time Setting is For the through phase is 10 sec., For the left-turn phase is 10 sec., and Detector Delay Time is 8 seconds.

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RULE203

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**SUBJECT:** DESIGN-RULES

If 1) The problem to be studied is DESIGN, and 2) The street type either major or minor is MINOR, and 3) speed on this approach is <35, and 4) the movement on this approach is LLT, or 2) the movement on this approach is LLTR, and 5) 1) the width of through lane is 11, or 2) The width of the first lane is 12, and 6) 1) the width of the second lane is 11, or 2) the width of the second lane is 12, and 7) 1) The width of the third lane is 11, or 2) The width of the third lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is \[\frac{\text{volume on this approach}}{15}\times 2.5\], and 2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 10], and 3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and 4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \[\frac{\text{peak-hour volume on the left-turn approach divided by 15}}{2.5}\], and 5) it is definite (100%) that detector type is The recommended detector
type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for the through lane and should be located at the stopline. For each left-turn lane a 6x25' LOOP is needed and should be placed at the stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: ON.

RULE204

SUBJECT: DESIGN-RULES

If 1) The problem to be studied is DESIGN, and 2) The street type either major or minor is MAJOR, or 3) The street type either major or minor is MINOR, and 4) speed on this approach is >35, and 5) The left turn movement is PROTECTED, and 6) 1) The width of the first lane is 11, or 2) The width of the first lane is 12, and 7) 1) The width of the second lane is 11, or 2) The width of the second lane is 12, and 8) 1) The width of the third lane is 11, or 2) The width of the third lane is 12, and 9) 1) The width of the fourth lane is 11, or 2) The width of the fourth lane is 12, and 10) 1) The width of the fifth lane is 11, or 2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; MAX I is [(The volume on this approach divided by 15) times 2.5], and 2) it is definite (100%) that MAX I Green Time is [Maximum green time for the through phase in sec.; MAX I plus 20], and 3) it is definite (100%) that MAX II is [MAX I Green Time plus 20], and 4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is [(The peak-hour volume on the left-turn approach divided by 15) times 2.5], and 5) it is definite (100%) that detector type is The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x20' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: OF.

RULE205

SUBJECT: DESIGN-RULES

If 1) The problem to be studied is DESIGN, and
2) The street type either major or minor is MINOR, and
3) speed on this approach is \( \leq 35 \), and
4) the movement on this approach is LTTTR, and
5) 1) the width of through lane is 11, or
   2) The width of the first lane is 12, and
6) 1) the width of the second lane is 11, or
   2) the width of the second lane is 12, and
7) 1) The width of the third lane is 11, or
   2) The width of the third lane is 12, and
8) 1) the width of the fourth lane is 11, or
   2) the width of the fourth lane is 12, and
9) 1) The width of the fifth lane is 11, or
   2) The width of the fifth lane is 12,

Then 1) it is definite (100%) that Maximum green time for the through phase in sec.; \( \text{MAX I} \) is \( \left( \frac{\text{the volume on this approach divided by 15}}{2.5} \right) \), and
2) it is definite (100%) that \( \text{MAX I} \) Green Time is \( \left( \frac{\text{Maximum green time for the through phase in sec.}}{\text{MAX I plus 10}} \right) \), and
3) it is definite (100%) that \( \text{MAX II} \) is \( \left( \frac{\text{MAX I Green Time plus 20}}{2.5} \right) \), and
4) it is definite (100%) that Maximum green time of the left-turn phase in sec. is \( \left( \frac{\text{the peak-hour volume on the left-turn approach divided by 15}}{2.5} \right) \), and
5) it is definite (100%) that detector type is The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for the through lane and should be located at the stopline. For each left-turn lane a 6x25' LOOP is needed and should be placed at the stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF

MEMORY: ON.
Frame :: MODIFICATION

IDENTIFIER :: MODIFICATION-
TRANSLATION :: (the unusual conditions)
PARENTS :: (TRAFFIC)
GOALS :: (DIME CONDITION DRIVE TYPE3)

PROMPTEVER ::
- LINE "* :ATTR (BLUE HIGH) "***************
   MODIFICATION STAGE "***************" :LINE 3 :ATTR (WHITE HIGH ) ":ATTR (MAGENTA HIGH) "Once the design state is complete, EXACT will allow you to make" :LINE 
   modifications on your design. These modifications include:* :LINE 2 " - Stopline Location"
   :LINE 
   - Lane Width" :LINE " - Pavement Condition" :LINE " - Driveway Presence" :LINE 3 :ATTR (YELLOW HIGH) 
   ***** GOOD LUCK WITH YOUR SESSION *****

PROMPT2ND :: (:LINE "Would you like to go over the modification stage again?"

DISPLAYRESULTS :: YES
PARMGROUP :: MODIFICATION-PARMS
RULEGROUPS :: (MODIFICATION-RULES)
MODIFICATION-PARMS :: (CONDITION CONSTRUCTION CURB DIME DRIVE DRIVEWAY
INSTALLATION LANE LANE1 MINE PAVECOND PAVEMENT STOPLIN)
MODIFICATION-RULES :: (RULE007 RULE053 RULE054 RULE055 RULE056 RULE057
RULE058 RULE059 RULE060 RULE061 RULE062 RULE063
RULE065 RULE066 RULE110 RULE185 RULE186 RULE189
RULE191 RULE192 RULE193 RULE194 RULE206 )

MODIFICATION-RULES

RULE007

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline 16-20)

If 1) The distance between the curbline and the stopline, and
2) the location of stopline is 16-20,
Then it is definite (100%) that the modification of the stopline location is
The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected..

RULE053

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width 9 or 10.)

If 1) Modification for lane width, and
2) The width of the lane is 10,
Then it is definite (100%) that the dimension of detectors with respect to
lane width is. For the LOOP design you will need a 5' x 25' loop to avoid
interference with adjacent traffic. This design will leave at least 2' between
the edge of the loop and the lane line. For the PROBE design two probes are adequate.

RULE054

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width = 13 ft.)
If 1) Modification for lane width, and
2) The width of the lane ? is 13,
Then it is definite (100%) that The dimension of detectors with respect to lane width is. For the LOOP design you will need a 7' x 25' loop to avoid interference with adjacent traffic. This design will leave 3' between the edge of the loop and the lane line. For the PROBE design two probes are adequate.

RULE055

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width = 14 or 15 ft.)
If 1) Modification for lane width, and
2) 1) The width of the lane ? is 14, or
2) The width of the lane ? is 15,
Then it is definite (100%) that The dimension of detectors with respect to lane width is. For the LOOP design you will need a 5' x 5' x 25' quadruple loop, which should be extended 5' ahead of the stopline. This design will leave at least 2' between the edge of the loop and the lane line to avoid interference with adjacent traffic. For the PROBE design two probes are adequate.

RULE056

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width = 16 ft.)
If 1) Modification for lane width, and
2) The width of the lane ? is 16,
Then it is definite (100%) that The dimension of detectors with respect to lane width is. For the LOOP design you will need a 5' x 5' x 25' quadruple loop, which should be extended 5' ahead of the stopline. This design will leave 3' between the edge of the loop and the lane line to avoid interference with adjacent traffic. For the PROBE design four probes are adequate.

RULE057

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width = 17 ft.)
If 1) Modification for lane width, and
2) The width of the lane ? is 17,
Then it is definite (100%) that The dimension of detectors with respect to lane width is. For the LOOP design you will need a 6' x 6' x 25' quadruple loop, which should be extended 5' ahead of the stopline. This design will leave 2.5' between the edge of the loop and the lane line to avoid the interference with adjacent traffic. For the PROBE design four probes are adequate.

RULE058

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width = 20 ft.)
If 1) Modification for lane width, and
2) The width of the lane is 20,
Then it is definite (100%) that the dimension of detectors with respect to lane width is For the LOOP design you will need two 6"x 25' loops. This design will leave 2.5' between the edge of the loop and the lane line. For the PROBE design five probes are adequate. However, you might want to divide this lane into two lanes if the geometric configuration of the intersection permits division.

RULE059

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width is not other than 11 or 12 ft.)
If it is not the case that Modification for lane width,
Then it is definite (100%) that The dimension of detectors with respect to lane width is The recommended initial design is based on 11 and 12' lanes.

RULE060

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline = 26 to 30)
If 1) The distance between the curbline and the stopline, and
2) the location of stopline is 26-30,
Then it is definite (100%) that The modification of the stopline location is The front of the loop should be extended 13 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

RULE061

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline = 31 to 35 ft.)
If 1) The distance between the curbline and the stopline, and
2) the location of stopline is 31-35,
Then it is definite (100%) that The modification of the stopline location is The front of the loop should be extended 18 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

RULE062

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline = 36 to 40 ft.)
If 1) The distance between the curbline and the stopline, and
2) the location of stopline is 36-40,
Then it is definite (100%) that The modification of the stopline location is The front of the loop should be extended 21 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

RULE063

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline = 41 to 45 ft.)
If 1) The distance between the curbline and the stopline, and
2) the location of stopline is 41-45,
Then it is definite (100%) that The modification of the stopline location is The front of the loop should be extended 28 ft. ahead of the stopline to ensure
that a proceeding vehicle will be detected.

RULE065

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Driveway Presence)
If Driveway around the intersection,
Then it is definite (100%) that Modification for driveway presence is There are two cases:

1. If the driveway abuts a MAJOR street, the design should be left as recommended, but the RECALL feature in the controller unit must be ON.

2. If the driveway abuts a MINOR street, the design will depend on the detection type:

   i) For presence detection leave the loop at the stopline.

   ii) For pulse detection (probes or small loops) detectors can be placed before the driveway, but you need to place a loop before the stopline as well so that the vehicles coming out of the driveway can be detected. This situation usually occurs on minor high speed approaches..

RULE066

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Pavement is not good.)
If 1) pavement condition : Is there any Problem ?, and
   2) 1) A description for pavement condition i.e. Cracks and so on. is CRACKS, or
      2) A description for pavement condition i.e. Cracks and so on. is POTHOLES,
Then it is definite (100%) that The modification for pavement conditions is You can take one of the following actions:

   a) Install a new small-loop or probes behind the stopline with LOCKING memory in the controller unit.

   b) Set the controller unit on minimum RECALL (e.g., 10 secs.) for that approach.

   c) Use a MICROWAVE detector on that approach.

   d) Call for special duty.

Notice that if the section of the pavement in which the loop is to be placed has three cracks of an inch or more, or three or more POTHOLES, do not install the loop on that section. In this case select one of the above solutions..

RULE110

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline > 45 ft.)
If 1) The distance between the curbline and the stopline, and
   2) the location of stopline is >45,
Then it is definite (100%) that The modification of the stopline location is
In this situation you have two choices: First, Use probes with memory ON. Second , instil a LOOP at the stopline but you need to install STOP HERE TO TRIP DETECT OR sign as well..

RULE185

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Pavement is not good and broken.)
If 1) pavement condition : Is there any Problem ?, and
2) A description for pavement condition i.e. Cracks and so on. is BROKEN,
Then it is definite (100%) that the modification for pavement conditions is
You need to stay away at least one foot from such broken pavement. If you can't
do so, You might take one of the following actions:

a) Install a new small-loop or probes back from the stopline with LOOKING
memory and can be placed 90-130 ft back from stopline.

b) Set the controller unit on minimum RECAL (10 sec.) for that approach.

c) Use a MICROWAVE detector on that approach.

d) Call for special duty..

RULE186

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Pavement is not good and Waving.)
If 1) pavement condition : Is there any Problem ?, and
2) A description for pavement condition i.e. Cracks and so on. is
CORRUGATIONS,
Then it is definite (100%) that the modification for pavement conditions is
If the pavement surface is waving the detector unit should be placed twice as
deep as in good pavement conditions. Alternatively, the detector unit can be
placed into a concrete base under the pavement surface in order to protect the
detector from lasting fast. You can also take one of the following actions:

a) Install a new small-loop or probes back from the stopline with LOOKING
memory.

b) Set the controller unit on minimum RECAL (10 sec.) for that approach.

c) Use a MICROWAVE detector on that approach.

d) Call for special duty..

RULE189

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Lane width = 18 or 19 ft.)
If 1) Modification for lane width, and
2) 1) The width of the lane ? is 18, or
2) The width of the lane ? is 19,
Then it is definite (100%) that the dimension of detectors with respect to
lane width is For LOOP design you need 2 6x20' loops. This design will leave
2.5' between the edge of the loop and the lane line. For PROBE design 4 probes
are adequate..
RULE191

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (No Driveway)
If Driveway around the intersection is not true,
Then it is definite (100%) that Modification for driveway presence is no
modification is needed for driveway presence.

RULE192

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Pavement is good)
If pavement condition : Is not there any Problem ?,
Then it is definite (100%) that The modification for pavement conditions is
No modification is needed for pavement condition.

RULE193

SUBJECT :: MODIFICATION-RULES
If 1) The distance between the curbline and the stopline, and
   2) the location of stopline is 21-25,
Then it is definite (100%) that The modification of the stopline location is
The front of the loop should be extended 8 ft. ahead of the stopline to ensure t
hat a proceeding vehicle will be detected.

RULE194

SUBJECT :: MODIFICATION-RULES
DESCRIPTION :: (Stopline <= 15 ft.)
If 1) The distance between the curbline and the stopline, and
   2) the location of stopline is <=15,
Then it is definite (100%) that The modification of the stopline location is
Two choices you have in this case: 1) Relocate the stopline to ensure a 15’
distance between the front of the loop and the curbline; this is more
preferable or 2) Keep a minimum distance 5’ between front of the loop and the
curbline.

RULE206

SUBJECT :: MODIFICATION-RULES
If The distance between the curbline and the stopline is not true,
Then it is definite (100%) that The modification of the stopline location is
No modification is needed for the stopline location.
Frame :: OPERATING

IDENTIFIER :: "OPERATING-"
TRANSLATION :: (This frame concerns with operational problems that the
traffic professional may face.)
PARENTS :: (TRAFFIC)
GOALS :: (RESULT3)
DISPLAYRESULTS :: YES
PARMGROUP :: OPERATING-PARMS
RULEGROUPS :: (OPERATING-RULES)
OPERATING-PARMS :: (RESULT3)
OPERATING-RULES :: (RULE169 RULE170 RULE171 RULE172 RULE173 RULE176
RULE177 RULE178 RULE179 RULE183 RULE184 )

OPERATING-RULES

RULE169

SUBJECT :: OPERATING-RULES
If  operational problems is WEATHER,
Then it is definite (100%) that the result of operational problems is

No changes in timing as weather conditions vary..

RULE170

SUBJECT :: OPERATING-RULES
If  1) operational problems is EQUIPMENT, and
  2) operating problems associated with equipment is POWER_OUTAGES,
Then it is definite (100%) that the result of operational problems is

City has on battery operated power supply (backup) which kicks on during AC
power outage. No changes are needed..

RULE171

SUBJECT :: OPERATING-RULES
If  operational problems is TREES,
Then it is definite (100%) that the result of operational problems is

1. Trim if they cover up lenses.
2. Install additional signal head if timing cannot be done.
3. Install ‘No Turn on Red’ sign if sight distance problem at corner..

RULE172

SUBJECT :: OPERATING-RULES
If operational problems is HORIZONTAL-CURVES, then it is definite (100%) that the result of operational problems is

Install additional signal head if stopping sight distance is violated.

RULE173

SUBJECT :: OPERATING-RULES

If 1) operational problems is EQUIPMENT, and
2) operating problems associated with equipment is CB-EQUIPMENT,
Then it is definite (100%) that the result of operational problems is

The possible problems are as follows:

1. If stuck signal, place on flash. Remove power from controller to see if this removes stuck condition.

2. If detector unit false calls, check the following:
   a) Is loop bad?
   b) Is sensitivity too high?
   c) Power down to reset unit.
   d) Replace detector.

3. If phase not being called, check the following:
   a) Is loop working?
   b) Is detector unit ok?
   c) Replace malfunctioning component.
   d) Place side street phase on recall if loop bad.

RULE176

SUBJECT :: OPERATING-RULES

If 1) operational problems is TRAFFIC, and
2) operating problems regarding traffic is CONSTRUCTION, and
3) 1) roadway closure is LANE_CLOSURE, or
   2) roadway closure is LOOP_DAMAGE, or
   3) roadway closure is DETOUR, or
   4) roadway closure is TRAFFIC_BEING_ROUTED,
Then 1) there is strongly suggestive evidence (90%) that the result of operational problems is THERE ARE THREE RECOMMENDED SOLUTIONS:

1. Put a phase on Maximum RECAL or increase green time for the phase suffering from the problem. Make sure this increase will not exceed MAX I. If traffic is back up you might increase MAX I too., and
2) there is strongly suggestive evidence (80%) that the result of operational problems is

2. Install a Time-Clock in the controller cabinet to give fixed green time every cycle for that approach where the problem is., and
3) there is suggestive evidence (50%) that the result of operational problems is

3. Install a MICROWAVE detector to replace the existing detector system.

RULE177

-------
SUBJECT :: OPERATING-RULES
If 1) operational problems is TRAFFIC, and
2) operating problems regarding traffic is SAFETY, and
3) operational safety problems is ACCIDENTS,
Then it is definite (100%) that the result of operational problems is

1. If number of left-turn accidents is greater than 5 per year, install left-turn phase.

2. If the dominant type of accidents is right angle, increase ALL-RED.

3. If the dominant type of accidents is rear-end, install backplates. Check maximum green to see if it is set high enough. It is recommended to install 12 inch RED LENSES.

RULE178

SUBJECT :: OPERATING-RULES
If 1) operational problems is TRAFFIC, and
2) operating problems regarding traffic is SAFETY, and
3) operational safety problems is CB-DAMAGE,
Then it is definite (100%) that the result of operational problems is

When CB is damaged by car accident possible solutions are:

1. Replace damaged components with new ones.

2. Install stop signs on side streets until signal functioning.

RULE179

SUBJECT :: OPERATING-RULES
If 1) operational problems is TRAFFIC, and
2) operating problems regarding traffic is SAFETY, and
3) operational safety problems is VANDALISM,
Then it is definite (100%) that the result of operational problems is

1. Gunshot in CB, replace damaged components inside CB.

2. Gunshots in lenses, replace lens.

RULE183

SUBJECT :: OPERATING-RULES
If 1) operational problems is TRAFFIC, and
2) operating problems regarding traffic is CONSTRUCTION, and
3) 1) roadway closure is SIDE STREET CLOSURE, or
2) roadway closure is ROADWAY CLOSURE,
Then 1) there is strongly suggestive evidence (90%) that the result of operational problems is There are tow recommended solutions:

1. Place signal on flash mode., and

2) there is suggestive evidence (60%) that the result of operational problems is

2. Call for on duty police to direct traffic.
If 1) operational problems is TRAFFIC, and

2) operating problems regarding traffic is CONGESTION,

Then 1) there is strongly suggestive evidence (90%) that the result of operational problems is

there are three recommended solutions:

1. Put a phase on Maximum RECAL or increase green time for the phase suffering from the problem. Make sure this increase will not exceed MAX I. If traffic is back up you might increase MAX I too., and

2) there is strongly suggestive evidence (80%) that the result of operational problems is

2. Install a Time-Clock in the controller cabinet to give fixed green time every cycle for that approach where the problem is., and

3) there is suggestive evidence (50%) that the result of operational problems is

3. Install a MICROWAVE detector to replace the existing detectoin system., and

4) inform the user of this decision.
APPENDIX C: Diagrams of Knowledge Base
PROBLEM

OPERATION

TRAFFIC

TREES

EQUIPMENT

WEATHER

SAFETY

CONGESTION

CONSTRUCTION

ACCIDENT

ROUTING

DETOUR

LOOP

SIDE STREET

LAINE CLOSURE

DAMAGE

CLOSURE

GOAL

GOAL

GOAL

GOAL

GOAL
MOVEMENT

LEFT-TURN MOVEMENT

PROTECTED/PERMITTED

PERMITTED

PROTECTED

% OF LEFT TURNS

\( \leq 5\% \)

GOAL

\( > 5\% \)

GOAL

GOAL
MODIFICATION SUBFRAME

STOPLINE

DRIVEWAY

PRESENCE

PAVEMENT

PROBLEMS

LANE

WIDTH

<15 16-20 21-25 26-30 ...... >45

YES NO NO YES NO 9 10 ....20

GOAL

GOAL

GOAL

GOAL

GOAL

GOAL

GOAL

GOAL

GOAL

GOAL

GOAL

CRACKS POTHOLE BROKEN CORRUGATIONS

GOAL

GOAL
APPENDIX D: Outside Experts Testing of EXACT
Case #1

Consultation record:

Consultation log: Expert System for ...

The problem to be studied: DESIGN
the location of the given intersection: TYPE I
The street type either main or minor: MAJOR
the speed on this approach: <= 35
the grade of this approach: <= 5% _LEVEL
the movement on this approach: T
the width of through lane (s): 11
the volume on this approach: 99
2: four approach subframe: NO
Modification for lane width: NO
pavement condition: Is there any Pr...: NO
Driveway around the intersection: NO
the location of stopline: 16-20
2: the unusual conditions: NO

^ = Through only
Conclusions for frame: DESIGN-1

**Detector Type** is as follows: The recommended detector type for this approach is a PROBE detector.

**Configuration:** TWO PROBES are needed for this approach and should be located 110 ft. behind the stopline.

**RECALL:** ON

**MEMORY:** ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

*Graphic output from file:* passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The **Minimum Green Time Setting** is as follows: 20 sec.

**MAX I Green Time** is as follows: 36.5

**MAX II is as follows:** 56.5

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case

The **recommended type of controller** is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12’ lanes

The modification for pavement conditions is as follows: "No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 5’ ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.
<table>
<thead>
<tr>
<th>Case #1</th>
<th>Agree</th>
<th>Disagree</th>
<th>Partial Agree and Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>DETECTOR Type, Location and Configuration</td>
<td>Agree 85%</td>
<td>The modification of 110% doesn't make sense - you can't extend deep 3 feet ahead of stop line using deeps - could be confusing.</td>
<td></td>
</tr>
<tr>
<td>Controller Type and Features</td>
<td></td>
<td>depending on the other approaches, I do not think an 8' controller is necessary for this approach.</td>
<td></td>
</tr>
<tr>
<td>Time Settings</td>
<td></td>
<td>this is difficult for me to judge and I am more familiar with dealing with specific cycle lengths.</td>
<td></td>
</tr>
</tbody>
</table>
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either main or minor :: MAJOR
speed on this approach :: >35
the grade of this approach :: <=5%_LEVEL
the movement on this approach :: T
the width of through lane (s) :: 11
The volume on this approach :: 99
The speed of the high speed approach :: 40
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: <=15
2:the unusual conditions :: NO

Case # 2

DESIGN
TYPE_I
MAJOR

LEVEL

>35

<=5%

T

11

99

40

NO

NO

NO

NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach. The exact locations of probes are given next.

RECALL: ON
MEMORY: OFF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage Time setting is 2.0 seconds.
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 220 ft. behind the near probes.
The EXTENSION time for the far probes: 2.3 sec.
The Minimum Green Time Setting is as follows: 20 sec.
MAX I Green Time is as follows: 31.5
MAX II is as follows: 46.5

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case.
The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12’ lanes.
The modification for pavement conditions is as follows: No modification is needed for pavement condition.
Modification for driveway presence is as follows: No modification is needed for driveway presence.
The modification of the stopline location is as follows: Two choices you have in this case: 1) Relocate the stopline to ensure a 15’ distance between the front of the loop and the curbline; this is more preferable or 2) Keep a minimum distance 5’ between front of the loop and the curbline.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
**Case #12**

<table>
<thead>
<tr>
<th>DETECTOR Type, Location and Configuration</th>
<th>Agree</th>
<th>Disagree/why</th>
<th>Partially Agree/why</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reasonable</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Controller Type and Features**

- We do not use these types of controllers.
- As it is hard for me to comment.

**Time Settings**

- OK.
The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ...
   The problem to be studied     : DESIGN
   the location of the given intersection : TYPE_I
   The street type either main or minor : MAJOR
   speed on this approach          : <=35
   the grade of this approach      : <=5%_LEVEL
   the movement on this approach   : LATR
   The left turn movement          : PROTECTED
   The width of the first lane     : 11
   the width of the second lane    : 11
   The volume on this approach     : 99
   The peak-hour volume on the left-turn ... : 45
   2:four approach subframe        : NO
   Modification for lane width     : NO
   pavement condition : Is there any Pr... : NO
   Driveway around the intersection : NO
   the location of stopline        : 16-20
   2:the unusual conditions        : NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector types for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.

CONFIGURATION: TWO PROBES are needed for this approach. They should be located 110 ft. behind the stopline. For the left-turn lane a 6' x 20' LOOP detector should be placed 20 ft. behind the stopline; this design is considered a second car detection.

RECALL: ON
MEMORY: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: For the through phase, 20 secs.; for the left-turn phase, 10 secs. Detector Delay Time is 8 secs.

MAX I Green Time is as follows: 36.5

MAX II is as follows: 56.5

Maximum green time of the left-turn phase in sec. is as follows: 7.5

The recommended type of controller is as follows: A Full-Actuated Controller Unit.

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes.

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
<table>
<thead>
<tr>
<th>DETECTOR Type, Location and Configuration</th>
<th>Agree</th>
<th>Disagree</th>
<th>Partial Agree and Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three bare detection seems reasonable (same as Case #1) You have 2 different detectors but which is on recall? The &quot;REAL&quot;Repair? The &quot;REAL&quot; is unclear when you have 2 loops</td>
<td></td>
<td></td>
<td>60%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Controller Type and Features</th>
<th></th>
<th>full evaluated OK</th>
<th>partial modification confusing</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Time Settings</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
</table>
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for...

The problem to be studied : DESIGN
the location of the given intersection : TYPE I
The street type either main or minor : MAJOR
speed on this approach : <=35
the grade of this approach : <=5% LEVEL
the movement on this approach : LATR
The left turn movement : PERMITTED
What is the left-turn % for the peak... : <=5%
The width of the first lane : 11
the width of the second lane : 11
The volume on this approach : 99
2: four approach subframe : NO
Modification for lane width : NO
pavement condition : Is there any Pr... : NO
Driveway around the intersection : NO
the location of stopline : 16-20
2: the unusual conditions : NO
Conclusions for frame: DESIGN-1

**Detectortype** is as follows: The recommended detector type for this approach is a PROBE detector for the through-movement lane.

**CONFIGURATION**: TWO PROBES are needed for this approach and should be located 110 ft. behind the stop line. Left-turning traffic is very light; therefore, it can be handled through gaps in the opposing traffic or in the yellow interval. Hence, no detector is needed.

**RECALL**: ON

**MEMORY**: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The **Minimum Green Time Setting** is as follows: 20 sec.

**MAX I Green Time is as follows**: 36.5

**MAX II is as follows**: 56.5

Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stop line location is as follows: The front of the loop should be extended 3 ft. ahead of the stop line to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to
<table>
<thead>
<tr>
<th>DETECTOR Type, Location and Configuration</th>
<th>Agree</th>
<th>Disagree</th>
<th>Partial Agree and Why?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controller Type and Features</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Settings</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Case #5**

the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ...
The problem to be studied ...
the location of the given intersection ...
The street type either main or minor ...
speed on this approach ...
the grade of this approach ...
the movement on this approach ...
The left turn movement ...
What is the left-turn % for the peak ...
The width of the first lane ...
the width of the second lane ...
The volume on this approach ...
2: four approach subframe ...
Modification for lane width ...
pavement condition : Is there any Pr ...
Driveway around the intersection ...
the location of stopline ...
2: the unusual conditions ...
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector types for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.

CONFIGURATION: Two PROBES are needed for the through lane and should be located 110 ft. behind the stopline. For the left-turn lane a 6’x 25’ LOOP detector should be placed at the stopline. The head of the loop should be extended 5’ ahead of the stopline.

RECALL: ON

MEMORY: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 36.5

MAX II is as follows: 56.5

Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended intial design is based on 11 and 12’ lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 8 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
<table>
<thead>
<tr>
<th>DETECTOR Type, Location, and Configuration</th>
<th>Agree</th>
<th>Disagree</th>
<th>Partial Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>90%</td>
</tr>
</tbody>
</table>

**Controller Type and Features**

**Time Settings**

Note: Use the back side for more comments.
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE 1
The street type either main or minor :: MINOR
speed on this approach :: <=15
the grade of this approach :: <=5% LEVEL
the movement on this approach :: LTTTR
The left turn movement :: PROTECTED
The width of the first lane :: 11
the width of the second lane :: 11
The width of the third lane :: 11
the width of the fourth lane :: 11
The volume on this approach :: 99
The peak-hour volume on the left-turn ... :: 55
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2:the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for each lane for this approach and should be located at the stopline. The front of the loop should be extended 5' ahead of the stopline.

RECALL: OFF.

MEMORY: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 10 sec.

MAX I Green Time is as follows: 26.5

MAX II is as follows: 36.5

Maximum green time of the left-turn phase in sec. is as follows: 9.166666666666667

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.
<table>
<thead>
<tr>
<th>Case #</th>
<th>Agree</th>
<th>Disagree/Why</th>
<th>Partial Agree/Why</th>
</tr>
</thead>
<tbody>
<tr>
<td>DETECTOR Type, Location, and Configuration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Controller Type and Features</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Settings</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Use the back side for more comments.

Note: 107°.

Diagram with notes: "Assuming the lift is moving..."
APPENDIX  E:  Our Expert's Testing of Knowledge Base
Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE_I
The street type either main or minor :: MAJOR
speed on this approach :: >35
the grade of this approach :: <=5%_LEVEL
the movement on this approach :: TT
The width of the first lane :: 12
the width of the second lane :: 12
The volume on this approach :: 297
The speed of the high speed approach :: 50
2: four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2: the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next.

RECALL: ON

MEMORY: OF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage Time setting is 2.0 seconds

The NEAR PROBES should be located 110 ft. behind the stopline.

The FAR PROBES should be located 293 ft. behind the near probes.

The EXTENSION time for the far probes: 2.5 sec.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 69.5

MAX II is as follows: 89.5

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case

The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
CITY OF COLUMBUS
DIV. OF TRAFFIC ENGINEERING & PARKING

STREET(S) : BROAD ST
LOCATION : WEST OF ROSE HILL RD
DIRECTION : EASTBOUND
MAP COORDINATE : L 24

DATE(S) : JUNE 4 & 5, 1990
DAY(S) OF WEEK : MON & TUES
WEATHER : CLEAR & DRY
MACHINE NUMBER : 86-02
TABULATED BY : JMR/TWM
STARTING TIME : 11:00 A.M.
COMMENTS : 0

ONE-HOUR 15 MIN. PERIOD STARTING ONE-HOUR PERIOD OF
PERIOD :00 :15 :30 :45 TOTALS TOTAL

12:00 AM 167 56 42 32 297 2.03
1:00 AM 18 20 17 18 73 0.50
2:00 AM 24 10 8 11 53 0.36
3:00 AM 4 12 9 10 35 0.24
4:00 AM 3 8 10 9 30 0.21
5:00 AM 15 15 32 26 88 0.60
6:00 AM 60 77 106 113 356 2.43
7:00 AM 148 139 107 118 512 3.50
8:00 AM 133 107 156 129 525 3.59
9:00 AM 93 98 132 128 451 3.08
10:00 AM 128 131 124 150 533 3.64
11:00 AM 194 181 192 138 725 4.94
12:00 PM 165 196 162 165 688 4.70
1:00 PM 180 173 160 130 643 4.40
2:00 PM 179 182 215 199 775 5.30
3:00 PM 252 319 165 143 2156 10.14
4:00 PM 58 424 441 507 1975 13.51
5:00 PM 133 138 503 479 2039 13.94
6:00 PM 368 256 210 185 1019 6.97
7:00 PM 161 204 154 159 678 4.64
8:00 PM 135 144 143 142 565 3.86
9:00 PM 122 140 105 118 485 3.32
10:00 PM 92 99 80 71 342 2.34
11:00 PM 58 71 66 99 233 1.73

TOTAL 24 HOUR 14623 13453 = ADT

FIVE HOUR TOTAL 6534 24/5 FACTOR 2.2380
(7-9 AM & 3-6 PM)

EIGHT HOUR TOTAL 8293 24/8 FACTOR 1.7633
(7-11 AM & 2-6 PM)

TWELVE HOUR TOTAL 10705 24/12 FACTOR 1.3660
(6:00 AM TO 6:00 PM)

AM PEAK HOUR VOLUME IS 725 FROM 11:00 AM TO 12:00 NOON
PM PEAK HOUR VOLUME IS 2067 FROM 4:45 PM TO 5:45 PM
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... :: DESIGN
The problem to be studied :: TYPE I
the location of the given intersection :: MAJOR
speed on this approach :: >35
the grade of this approach :: <=5% LEVEL
the movement on this approach :: PERMITTED
The left turn movement :: 1ATT
What is the left-turn % for the peak... :: >5%
The width of the first lane :: 11
the width of the second lane :: 12
The width of the third lane :: 12
The volume on this approach :: 210
The speed of the high speed approach :: 50
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2:the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high-speed approach; therefore, the dilemma zone technique should be implemented. Two NEAR probes and two FAR probes are needed for this approach per lane. The exact locations of these probes will be detailed shortly. In addition, a 6’ x 25’ LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located 20’ behind the stopline.

RECALL: ON

MEMORY: OF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage Time setting is 2.0 seconds. The NEAR PROBES should be located 110 ft. behind the stopline. The FAR PROBES should be located 293 ft. behind the near probes. The EXTENSION time for the far probes: 2.5 sec.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 55.

MAX II is as follows: 75.

Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case.

The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12’ lanes.

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
CITY OF COLUMBUS
DIV. OF TRAFFIC ENGINEERING & PARKING

STREET(S) : BROAD ST
LOCATION : EAST OF ROSE HILL RD
DIRECTION : WESTBOUND
MAP COORDINATE : L 24

DATE(S) : JUNE 4 & 5, 1990
DAY(S) OF WEEK : MON & TUES
WEATHER : CLEAR & DRY
MACHINE NUMBER : 95-24
TABULATED BY : JMR/TWM
STARTING TIME : 11:00 A.M.
COMMENTS : CH 1=W/B TOTAL TRAFFIC

<table>
<thead>
<tr>
<th>ONE-HOUR PERIOD</th>
<th>15 MIN. PERIOD STARTING</th>
<th>ONE-HOUR PERIOD TOTALS</th>
<th>PERCENT OF TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>STARTING</td>
<td>:00</td>
<td>:15</td>
<td>:30</td>
</tr>
<tr>
<td>12:00 AM</td>
<td>22</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>1:00 AM</td>
<td>15</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>3:00 AM</td>
<td>8</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>4:00 AM</td>
<td>13</td>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>5:00 AM</td>
<td>36</td>
<td>32</td>
<td>102</td>
</tr>
<tr>
<td>6:00 AM</td>
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<td>258</td>
<td>339</td>
</tr>
<tr>
<td>7:00 AM</td>
<td>359</td>
<td>419</td>
<td>346</td>
</tr>
<tr>
<td>8:00 AM</td>
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<td>196</td>
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<td>156</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>142</td>
<td>139</td>
<td>157</td>
</tr>
<tr>
<td>11:00 AM</td>
<td>111</td>
<td>128</td>
<td>172</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>148</td>
<td>141</td>
<td>160</td>
</tr>
<tr>
<td>1:00 PM</td>
<td>157</td>
<td>176</td>
<td>153</td>
</tr>
<tr>
<td>2:00 PM</td>
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<td>4:00 PM</td>
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<td>183</td>
</tr>
<tr>
<td>6:00 PM</td>
<td>135</td>
<td>182</td>
<td>143</td>
</tr>
<tr>
<td>7:00 PM</td>
<td>115</td>
<td>90</td>
<td>69</td>
</tr>
<tr>
<td>8:00 PM</td>
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<tr>
<td>10:00 PM</td>
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<td>53</td>
</tr>
<tr>
<td>11:00 PM</td>
<td>45</td>
<td>45</td>
<td>33</td>
</tr>
</tbody>
</table>

TOTAL 24 HOUR 11950

FIVE HOUR TOTAL 4672 24/5 FACTOR 2.5578
(7-9 AM & 3-6 PM)

EIGHT HOUR TOTAL 6588 24/8 FACTOR 1.8139
(7-11 AM & 2-6 PM)

TWELVE HOUR TOTAL 9499 24/12 FACTOR 1.2580
(6:00 AM TO 6:00 PM)

AM PEAK HOUR VOLUME IS 1509 FROM 6:45 AM TO 7:45 AM
PM PEAK HOUR VOLUME IS 794 FROM 3:00 PM TO 4:00 PM
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either main or minor :: MINOR
speed on this approach :: <=35
the grade of this approach :: <=5\% LEVEL
the movement on this approach :: LTTT
The width of the first lane :: 11
the width of the second lane :: 11
The volume on this approach :: 169
2: four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2: the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane and should be located at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF
MEMORY: C

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 10 sec.

MAX I Green Time is as follows: 38.166666666667

MAX II is as follows: 58.166666666667

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended intial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3 ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.
**City of Columbus**  
**Div. of Traffic Engineering & Parking**

**Street(s):** ALUM CREEK DR  
**Location:** SOUTH OF LIVINGSTON AV  
**Direction:** NORTHBOUND  
**Map Coordinate:** 0 18  
**Date(s):** JAN 10 & 11, 1991  
**Day(s) of Week:** THURS & FRI  
**Weather:** RAIN  
**Machine Number:** 86-02  
**Tabulated By:** TWM  
**Starting Time:** 9:45 A.M.  
**Comments:** CH 1=TOTAL N/B TRAFFIC

<table>
<thead>
<tr>
<th>One-Hour 15 Min. Period Starting</th>
<th>One-Hour Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starting</strong></td>
<td>00</td>
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<tr>
<td>12:00 AM</td>
<td>39</td>
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<td>1:00 AM</td>
<td>39</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>21</td>
</tr>
<tr>
<td>3:00 AM</td>
<td>17</td>
</tr>
<tr>
<td>4:00 AM</td>
<td>17</td>
</tr>
<tr>
<td>5:00 AM</td>
<td>15</td>
</tr>
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</tr>
<tr>
<td>9:00 AM</td>
<td>148</td>
</tr>
<tr>
<td>10:00 AM</td>
<td>135</td>
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<td>11:00 AM</td>
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<tr>
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<td>90</td>
</tr>
<tr>
<td>11:00 PM</td>
<td>67</td>
</tr>
</tbody>
</table>

**Total 24 Hour:** 14584  
**Total 5 Hour Factor:** 4995 24/5 Factor 2.9197  
**Total 8 Hour Factor:** 7345 24/8 Factor 1.9856  
**Total 12 Hour Factor:** 10765 24/12 Factor 1.3548  

**AM Peak Hour Volume IS:** 831  
**PM Peak Hour Volume IS:** 1297  
**From 11:15 AM to 12:15 PM:**  
**From 5:00 PM to 6:00 PM:**
Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE_I
The street type either main or minor :: MINOR
speed on this approach :: <=15
the grade of this approach :: <=5%_LEVEL
the movement on this approach :: TL
the width of through lane (s) :: 11
The volume on this approach :: 123
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 21-25
2:the unusual conditions :: NO
Inclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a LOOP DETECTOR.

CONFIGURATION: A 6' x 25' LOOP is needed for this approach and should be extended 5' ahead of the stopline.

RECALL: OFF

MEMORY: ON

DETECTOR TIME-DELAY = 8 sec.

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 10 sec.

MAX I Green Time is as follows: 30.5

MAX II is as follows: 40.5

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 5' ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to
<table>
<thead>
<tr>
<th>ONE-HOUR PERIOD</th>
<th>15 MIN. PERIOD</th>
<th>STARTING</th>
<th>ONE-HOUR PERIOD</th>
<th>PERCENT OF TOTAL</th>
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<tr>
<td>STARTING :00</td>
<td>:15 :30 :45</td>
<td></td>
<td>TOTALS</td>
<td></td>
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<tr>
<td>12:00 AM</td>
<td>11 10 13 12</td>
<td>46</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>1:00 AM</td>
<td>9 9 4 6</td>
<td>28</td>
<td>0.76</td>
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</tr>
<tr>
<td>2:00 AM</td>
<td>6 6 21 1</td>
<td>34</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>3:00 AM</td>
<td>6 5 4 2</td>
<td>17</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>4:00 AM</td>
<td>2 2 3 6</td>
<td>13</td>
<td>0.35</td>
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</tr>
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<td>5:00 AM</td>
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<td>42</td>
<td>1.14</td>
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<td>6:00 AM</td>
<td>12 27 44 29</td>
<td>112</td>
<td>3.03</td>
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<tr>
<td>7:00 AM</td>
<td>42 44 60 43</td>
<td>189</td>
<td>5.12</td>
<td></td>
</tr>
<tr>
<td>8:00 AM</td>
<td>64 49 48 33</td>
<td>194</td>
<td>5.25</td>
<td></td>
</tr>
<tr>
<td>9:00 AM</td>
<td>41 27 30 39</td>
<td>137</td>
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<tr>
<td>11:00 AM</td>
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<td>147</td>
<td>3.98</td>
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</tr>
<tr>
<td>12:00 PM</td>
<td>53 47 42 50</td>
<td>192</td>
<td>5.20</td>
<td></td>
</tr>
<tr>
<td>1:00 PM</td>
<td>57 58 41 47</td>
<td>203</td>
<td>5.50</td>
<td></td>
</tr>
<tr>
<td>2:00 PM</td>
<td>58 71 77 57</td>
<td>263</td>
<td>7.12</td>
<td></td>
</tr>
<tr>
<td>3:00 PM</td>
<td>71 75 88 72</td>
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<tr>
<td>4:00 PM</td>
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<td>5:00 PM</td>
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<td>412</td>
<td>11.16</td>
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</tr>
<tr>
<td>6:00 PM</td>
<td>61 50 48 46</td>
<td>205</td>
<td>5.55</td>
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</tr>
<tr>
<td>7:00 PM</td>
<td>51 41 43 45</td>
<td>190</td>
<td>4.88</td>
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<tr>
<td>8:00 PM</td>
<td>46 29 30 39</td>
<td>144</td>
<td>3.90</td>
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</tr>
<tr>
<td>9:00 PM</td>
<td>40 20 32 30</td>
<td>122</td>
<td>3.30</td>
<td></td>
</tr>
<tr>
<td>10:00 PM</td>
<td>28 22 27 24</td>
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<tr>
<td>11:00 PM</td>
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<td>106</td>
<td>2.87</td>
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</tr>
<tr>
<td>TOTAL 24 HOUR</td>
<td></td>
<td>3692</td>
<td>4283 = ADT</td>
<td></td>
</tr>
</tbody>
</table>

FIVE HOUR TOTAL 1460 24/5 FACTOR 2.5288
(7-9 AM & 3-6 PM)

EIGHT HOUR TOTAL 2000 24/8 FACTOR 1.8460
(7-11 AM & 2-6 PM)

TWELVE HOUR TOTAL 2654 24/12 FACTOR 1.3911
(6:00 AM TO 6:00 PM)

AM PEAK HOUR VOLUME IS 216 FROM 7:30 AM TO 8:30 AM
PM PEAK HOUR VOLUME IS 431 FROM 4:45 PM TO 5:45 PM
the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either main or minor :: MAJOR
speed on this approach :: <=35
the grade of this approach :: <=5\% LEVEL
the movement on this approach :: LATR
The left turn movement :: PERMITTED
What is the left-turn % for the peak... :: >5\%
The width of the first lane :: 11
the width of the second lane :: 11
The volume on this approach :: 164
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: 16-20
2:the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector types for this approach are a PROBE detector for the through-movement lane and a LOOP detector for the left-turn lane.

CONFIGURATION: Two PROBES are needed for the through lane and should be located 110 ft. behind the stopline. For the left-turn lane a 6'x 25' LOOP detector should be placed at the stopline. The head of the loop should be extended 5' ahead of the stopline.

RECALL: ON
MEMORY: OFF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 20 sec.
MAX I Green Time is as follows: 47.333333333333
MAX II is as follows: 67.333333333333

Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 5' ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
CITY OF COLUMBUS  
DIV. OF TRAFFIC ENGINEERING & PARKING  

STREET(S): LEONARD AV  
LOCATION: EAST OF CHAMPION AV  
DIRECTION: WESTBOUND  
MAP COORDINATE: L 17  

DATE(S): SEPT 20 & 21, 1990  
DAY(S) OF WEEK: THURS & FRI  
WEATHER: CLEAR & DRY  
MACHINE NUMBER: 85-21  
TABULATED BY: TWM  
STARTING TIME: 9:45 A.M.  
COMMENTS: COMPUTER  
FILE NAME: 90201 -1

### One-Hour Period Totals

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<tr>
<th>Period Starting</th>
<th>100</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>TOTALS</th>
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<tbody>
<tr>
<td>12:00 AM</td>
<td>23</td>
<td>26</td>
<td>18</td>
<td>21</td>
<td>88</td>
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<td>31</td>
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<tr>
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<td>15</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>5:00 AM</td>
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<td>33</td>
<td>92</td>
<td>208</td>
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<tr>
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<td>93</td>
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<td>200</td>
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<td>654</td>
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<td>219</td>
<td>178</td>
<td>194</td>
<td>830</td>
</tr>
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<td>145</td>
<td>139</td>
<td>122</td>
<td>140</td>
<td>566</td>
</tr>
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<td>104</td>
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<td>123</td>
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<td>12:00 PM</td>
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<td>543</td>
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<td>168</td>
<td>148</td>
<td>560</td>
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<td>141</td>
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<td>191</td>
<td>174</td>
<td>673</td>
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<td>318</td>
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<td>764</td>
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<td>65</td>
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<td>11:00 PM</td>
<td>50</td>
<td>44</td>
<td>55</td>
<td>48</td>
<td>197</td>
</tr>
</tbody>
</table>

**Total 24 Hour** 10299

**Percent of Total:**

- 0.85
- 0.52
- 0.30
- 0.56
- 2.02
- 6.35
- 9.16
- 3.06
- 5.50
- 4.66
- 4.87
- 5.27
- 5.44
- 5.86
- 6.53
- 7.42
- 7.25
- 5.30
- 4.26
- 2.53
- 2.29
- 2.53
- 1.91

**Total ADT** 9527

**24/5 Factor** 2.6027

**24/6 Factor** 1.8368

**24/12 Factor** 1.3093

*AM Peak Hour Volume IS 1000 From 7:15 AM TO 8:15 AM*  
*PM Peak Hour Volume IS 798 From 4:15 PM TO 5:15 PM*
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

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<tr>
<th>Consultation log: Expert System for ...</th>
<th>DESIGN</th>
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</thead>
<tbody>
<tr>
<td>The problem to be studied</td>
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<tr>
<td>the location of the given intersection</td>
<td>MINOR</td>
</tr>
<tr>
<td>The street type either main or minor</td>
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</tr>
<tr>
<td>speed on this approach</td>
<td>&lt;=5%</td>
</tr>
<tr>
<td>the grade of this approach</td>
<td>LEVEL</td>
</tr>
<tr>
<td>the movement on this approach</td>
<td>LATR</td>
</tr>
<tr>
<td>The left turn movement</td>
<td>PERMITTED</td>
</tr>
<tr>
<td>The width of the first lane</td>
<td>11</td>
</tr>
<tr>
<td>the width of the second lane</td>
<td>11</td>
</tr>
<tr>
<td>The volume on this approach</td>
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<td>2:four approach subframe</td>
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<td>Modification for lane width</td>
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</tr>
<tr>
<td>pavement condition: Is there any Pr...</td>
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</tr>
<tr>
<td>Driveway around the intersection</td>
<td>&lt;=15</td>
</tr>
<tr>
<td>the location of stopline</td>
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</tr>
<tr>
<td>2:the unusual conditions</td>
<td>NO</td>
</tr>
</tbody>
</table>
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane and should be located at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF

MEMORY: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 10 sec.

MAX I Green Time is as follows: 43.83333333333333

MAX II is as follows: 63.83333333333333

Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended initial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: Two choices you have in this case: 1) Relocate the stopline to ensure a 15' distance between the front of the loop and the curbline; this is more preferable or 2) Keep a minimum distance 5' between front of the loop and the curbline.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to
**CITY OF COLUMBUS**
**DIV. OF TRAFFIC ENGINEERING & PARKING**

**STREET(S):** ALUM CREEK DR  
**LOCATION:** SOUTH OF MAIN ST  
**DIRECTION:** NORTHBOUND  
**MAP COORDINATE:** N 18

**DATE(S):** JAN 9 & 10, 1991  
**DAY(S) OF WEEK:** WED & THURS  
**WEATHER:** RAIN  
**MACHINE NUMBER:** B5-25  
**TABULATED BY:** TWM  
**STARTING TIME:** 6:45 P.M.

**COMMENTS:** CH 1=TOTAL N/B TRAFFIC

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<th>STARTING</th>
<th>PERIOD</th>
<th>ONE-HOUR</th>
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<td>30</td>
<td>45</td>
<td>TOTALS</td>
</tr>
<tr>
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<td>22</td>
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<td>1.11</td>
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<td>0.87</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>2:00</td>
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**TOTAL 24 HOUR** 7692  
**24/5 FACTOR** 2.7248  
**7692 = ADT**

**FIVE HOUR TOTAL** 2823  
**24/5 FACTOR** 2.7248  
**EIGHT HOUR TOTAL** 4056  
**24/8 FACTOR** 1.8964  
**TWELVE HOUR TOTAL** 5563  
**24/12 FACTOR** 1.3827  

**AM PEAK HOUR VOLUME IS 467 FROM 11:15 AM TO 12:15 PM**  
**PM PEAK HOUR VOLUME IS 833 FROM 5:15 PM TO 6:15 PM**
the initial design. The next menu will have various options.

Consultation record:

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</tr>
<tr>
<td>The street type either main or minor</td>
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Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x20' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located at the stopline. The front of loop should be extended 5' ahead of the stopline.

RECALL: ON (Only)

MEMORY: OF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage Time setting is 2.0 seconds.

The NEAR PROBES should be located 110 ft. behind the stopline.

The FAR PROBES should be located 256 ft. behind the near probes.

The EXTENSION time for the far probes: 2.4 sec.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 46.6

MAX II is as follows: 66.6

Maximum green time of the left-turn phase in sec. is as follows:

The recommended type of controller is as follows: A Volume Density Controller Unit

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: Two choices you have in this case: 1) Relocate the stopline to ensure a 15' distance between the front of the loop and the curbline; this is more preferable or 2) Keep a minimum distance 5' between front of the loop and the curbline.

Conclusions for frame: DESIGN-1
CITY OF COLUMBUS
DIV. OF TRAFFIC ENGINEERING & PARKING

STREET(S) : DUBLIN RD (U.S. RT 33)
LOCATION : SOUTH OF FIFTH AV
DIRECTION : NORTHBOUND
MAP COORDINATE : L 11

DATE(S) : JULY 6 & 7, 1989
DAY(S) OF WEEK : THURS & FRI
WEATHER : CLEAR & DRY
MACHINE NUMBER : 85-20
TABULATED BY : TM
STARTING TIME : 9:45 A.M.
COMMENTS : CHANNEL 1 TOTAL N/B TRAFFIC

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TOTAL 24 HOUR: 12146

FIVE HOUR TOTAL: 4623 [24/5 FACTOR: 2.6273]
EIGHT HOUR TOTAL: 6533 [24/8 FACTOR: 1.8992]
TWELVE HOUR TOTAL: 9201 [24/12 FACTOR: 1.3201]

AM PEAK HOUR VOLUME IS 894 FROM 11:15 AM TO 12:15 PM
PM PEAK HOUR VOLUME IS 1533 FROM 4:45 PM TO 5:45 PM
the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either main or minor :: MAJOR
speed on this approach :: >35
the grade of this approach :: <=5% LEVEL
the movement on this approach :: LATTR
The left turn movement :: PROTECTED
The width of the first lane :: 11
the width of the second lane :: 12
The width of the third lane :: 12
The volume on this approach :: 161
The peak-hour volume on the left-turn ... :: 53
The speed of the high speed approach :: 45
2:four approach subframe :: NO
Modification for lane width :: NO
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: <=15
2:the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high speed approach, therefore, the dilemma-zone technique is applied. Two NEAR probes and two FAR probes are needed for this approach for each lane. The exact locations of probes are given next. A 6x20' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located at the stopline. The front of loop should be extended 5' ahead of the stopline.

RECALL: ON (Ηυ,νεζ Ψνυ) "0' λ'"

MEMORY: OF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows: The passage time setting is 2.0 seconds.

The NEAR PROBES should be located 110 ft. behind the stopline.

The FAR PROBES should be located 256 ft. behind the near probes.

The EXTENSION time for the far probes: 2.4 sec.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 46.833333333333

MAX II is as follows: 66.833333333333

Maximum green time of the left-turn phase in sec. is as follows:

6.833333333333

The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended intial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: Two choices you have in this case: 1) Relocate the stopline to ensure a 15' distance between the front of the loop and the curbline; this is more preferable or 2) Keep a minimum distance 5' between front of the loop and the curbline.

Conclusions for frame: TRAFFIC-1
CITY OF COLUMBUS
DIV. OF TRAFFIC ENGINEERING & PARKING

STREET(S) : FIFTH AV
LOCATION : EAST OF DUBLIN RD (U.S. 33)
DIRECTION : WESTBOUND
MAP COORDINATE : L 11

DATE(S) : JULY 6 & 7, 1989
DAY(S) OF WEEK : THURS & FRI
WEATHER : CLEAR & DRY
MACHINE NUMBER : 86-03
TABULATED BY : TWH
STARTING TIME : 10:00 A.M.
COMMENTS : CHANNEL 1 TOTAL W/B TRAFFIC

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<td>112</td>
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<td>11:00 PM</td>
<td>38</td>
<td>26</td>
<td>27</td>
<td>25</td>
</tr>
</tbody>
</table>

TOTAL 24 HOUR : 6477

FIVE HOUR TOTAL : 2326
24/5 FACTOR : 2.7846
(7-9 AM & 3-6 PM)

EIGHT HOUR TOTAL : 3358
24/8 FACTOR : 1.9288
(7-11 AM & 2-6 PM)

TWELVE HOUR TOTAL : 4861
24/12 FACTOR : 1.5324
(6:00 AM TO 6:00 PM)

AM PEAK HOUR VOLUME : 443 FROM 11:15 AM TO 12:15 PM
PM PEAK HOUR VOLUME : 609 FROM 4:45 PM TO 5:45 PM
The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ...
The problem to be studied   : DESIGN
the location of the given intersection : TYPE I
The street type either main or minor   : MINOR
speed on this approach  : <=35
the grade of this approach : <=5%_LEVEL
the movement on this approach : LTTR
The width of the first lane  : 11
the width of the second lane : 11
The volume on this approach : 124
2:four approach subframe : NO
Modification for lane width : NO
pavement condition : Is there any Pr... : NO
Driveway around the intersection : NO
the location of stopline : 16-20
2:the unusual conditions : NO
Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: This is a high-speed approach; therefore, the dilemma zone technique should be implemented. Two NEAR probes and two FAR probes are needed for this approach per lane. The exact locations of these probes will be detailed shortly. In addition, a 6' x 25' LOOP is needed for the left-turn lane to handle the left-turn traffic and should be located 20' behind the stopline.

RECALL: ON
MEMORY: OF

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as is as follows: The passage Time setting is 2.0 seconds
The NEAR PROBES should be located 110 ft. behind the stopline.
The FAR PROBES should be located 293 ft. behind the near probes.
The EXTENSION time for the far probes : 2.5 sec.
The Minimum Green Time Setting is as follows: 20 sec.
MAX I Green Time is as follows: 49.5
MAX II is as follows: 69.5
Maximum green time of the left-turn phase in sec. is as follows: No need for a left-turn phase in this case

The recommended type of controller is as follows: A Volume Density Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended intial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended (11') ft. ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
### Data Summary

#### Street(s):
BROAD ST

#### Location:
WEST OF CARDINAL PARK DR

#### Direction:
EASTBOUND

#### Map Coordinate:
L 22

#### Date(s):
MAR 7 & 8, 1991

#### Day(s) of Week:
THURS & FRI

#### Weather:
CLEAR & DRY

#### Machine Number:
85-24

#### Tabulated By:
TWM

#### Starting Time:
9:45 A.M.

#### File Name:
91077 -1

#### Comments:
CHANNEL I=TOTAL E/B TRAFFIC

### Traffic Volume

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<th>15 Min. Starting</th>
<th>700</th>
<th>7:45</th>
<th>7:30</th>
<th>7:45</th>
<th>TOTALS</th>
<th>Percent of Total</th>
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<td>14</td>
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<td>179</td>
<td>869</td>
<td>6.57</td>
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<td>133</td>
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</table>

**Total 24 Hour:** 13221

**Five Hour Total:** 5154 (7-9 AM & 3-6 PM) 24/5 Factor 2.5652

**Eight Hour Total:** 6962 (7-11 AM & 2-6 PM) 24/8 Factor 1.0990

**Twelve Hour Total:** 9554 (6:00 AM TO 6:00 PM) 24/12 Factor 1.3838

**AM Peak Hour Volume IS 660 FROM 11:15 AM TO 12:15 PM**

**PM Peak Hour Volume IS 1436 FROM 4:30 PM TO 5:30 PM**
Consultation record:

Consultation log: Expert System for ... : DESIGN
the problem to be studied : DESIGN
the location of the given intersection : TYPE_I
The street type either main or minor : MAJOR
speed on this approach : >35
the grade of this approach : <=5% LEVEL
the movement on this approach : LATT
The left turn movement : PERMITTED
What is the left-turn % for the peak... : >5%
The width of the first lane : 11
the width of the second lane : 12
The width of the third lane : 12
The volume on this approach : 177
The speed of the high speed approach : 50
2:four approach subframe : NO
Modification for lane width : NO
pavement condition : Is there any Pr... : NO
Driveway around the intersection : NO
the location of stopline : 26-30
2:the unusual conditions : NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a LOOP detector.

CONFIGURATION: A 6x25' LOOP is needed for this approach per lane and should be located at stopline. The head of loop should be extended 5' ahead of the stopline.

RECALL: OFF

MEMORY: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 10 sec.

MAX I Green Time is as follows: 30.666666666667

MAX II is as follows: 50.666666666667

Maximum green time of the left-turn phase in sec. is as follows: No left-turn phase in this case

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: The recommended intial design is based on 11 and 12' lanes

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: The front of the loop should be extended 3-ft, ahead of the stopline to ensure that a proceeding vehicle will be detected.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:

This concludes the design session including any modification you have made to the initial design. The next menu will have various options.
CITY OF COLUMBUS  
DIV. OF TRAFFIC ENGINEERING & PARKING

STREET(S) : FIFTH AV  
LOCATION : EAST OF NELSON RD  
DIRECTION : WESTBOUND  
MAP COORDINATE : L 18

DATE(S) : JAN 16 & 17, 1991  
DAY(S) OF WEEK : WED & THURS  
WEATHER : LT RAIN  
MACHINE NUMBER : 65-27  
TABULATED BY : TWM  
STARTING TIME : 9:45 A.M.  
COMMENTS : CH 1=TOTAL W/B TRAFFIC

<table>
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<th>PERIOD STARTING</th>
<th>ONE-HOUR PERIOD</th>
<th>PERCENT OF TOTAL</th>
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</thead>
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<td>1.03</td>
</tr>
<tr>
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<td>20 23 13 16</td>
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</tr>
<tr>
<td>2:00 AM</td>
<td>12 15 14 6</td>
<td>0.40</td>
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<td>3:00 AM</td>
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</tr>
<tr>
<td>4:00 AM</td>
<td>12 15 8 24</td>
<td>0.50</td>
</tr>
<tr>
<td>5:00 AM</td>
<td>23 44 56 78</td>
<td>1.70</td>
</tr>
<tr>
<td>6:00 AM</td>
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<td>5.21</td>
</tr>
<tr>
<td>12:00 PM</td>
<td>140 134 165 157</td>
<td>5.21</td>
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</tr>
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</tr>
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<td>2.21</td>
</tr>
<tr>
<td>11:00 PM</td>
<td>59 43 50 67</td>
<td>1.85</td>
</tr>
</tbody>
</table>

TOTAL 24 HOUR : 11834  

FIVE HOUR TOTAL : 4554  
FACTOR : 2.5986  
(7-9 AM & 3-6 PM)

EIGHT HOUR TOTAL : 6500  
FACTOR : 1.8206  
(7-11 AM & 2-6 PM)

TWELVE HOUR TOTAL : 9071  
FACTOR : 1.3046  
(6:00 AM TO 6:00 PM)

AM PEAK HOUR VOLUME IS 1354 FROM 7:00 AM TO 8:00 AM  
PM PEAK HOUR VOLUME IS 778 FROM 3:00 PM TO 4:00 PM
This concludes the design session including any modification you have made to the initial design. The next menu will have various options.

Consultation record:

Consultation log: Expert System for ... ::
The problem to be studied :: DESIGN
the location of the given intersection :: TYPE I
The street type either main or minor :: MAJOR
speed on this approach :: <=35
the grade of this approach :: <=5% LEVEL
the movement on this approach :: LATTR
The left turn movement :: PROTECTED
The width of the first lane :: 11
the width of the second lane :: 11
The width of the third lane :: 11
The volume on this approach :: 108
The peak-hour volume on the left-turn ... :: 163
2: four approach subframe :: NO
Modification for lane width :: YES
The width of the lane ? :: 10
pavement condition : Is there any Pr... :: NO
Driveway around the intersection :: NO
the location of stopline :: =<15
2: the unusual conditions :: NO
Conclusions for frame: DESIGN-1

Detector type is as follows: The recommended detector type for this approach is a PROBE detector.

CONFIGURATION: Two probes are needed per the inside lane and two probes per the middle lane. All probes should be LOCATED 110 ft. behind the stopline. For the protected left-turn lane a 6x20’ ft. loop is needed and to be installed at the stopline. The head of loop should be extended 5’ ahead of the stopline.

RECALL: ON  
MEMORY: ON

The PASSAGE TIME is given but first a chart will appear to illustrate the relationship between passage time, grade, and the location of the intersection. This chart is as follows:

Graphic output from file: passage 2.5-3.0 secs. of passage time is the suggested range. Our expert suggests 2.5 secs. as the value that should be set into the controller unit to ensure snappy operation.

The Minimum Green Time Setting is as follows: 20 sec.

MAX I Green Time is as follows: 38.

MAX II is as follows: 58.

Maximum green time of the left-turn phase in sec. is as follows:

The recommended type of controller is as follows: A Full-Actuated Controller Unit

Conclusions for frame: MODIFICATION-1

The dimension of detectors with respect to lane width is as follows: For the LOOP design you will need a 5’ x 25’ loop to avoid interference with adjacent traffic. This design will leave at least 2’ between the edge of the loop and the lane line. For the PROBE design two probes are adequate.

The modification for pavement conditions is as follows: No modification is needed for pavement condition.

Modification for driveway presence is as follows: No modification is needed for driveway presence.

The modification of the stopline location is as follows: Two choices you have in this case: 1) Relocate the stopline to ensure a 15’ distance between the front of the loop and the curbline; this is more preferable or 2) Keep a minimum distance 5’ between front of the loop and the curbline.

Conclusions for frame: TRAFFIC-1

The last comment is as follows:
**Action** - A rule's then statement, which specifies the action that PC Plus perform if the rule's permise, or IF statement, passes.

**Actuated Controller** - A controller for supervising the operation of traffic control signals in accordance with the varying demands of traffic as registered with the controller by traffic detectors.

**Actuation** - The operation of any type of detector (NEMA). The word operation means an output from the detector to the controller unit.

**ARL Language** - Abbreviated Rule Language (ARL) is the language in which the knowledge engineer can enter PC Plus rules. Its form consists of parameter names, values, and possibly functions.

#:ATTR - A formatting command used to change the attributes of text that follows this command. The command allows the developer to specify underlining, or blinking to display the text in a specified color or intensity.

**Backward Chaining** - The primary method PC Plus uses to determine the value of a goal parameter. Using backward chaining, PC Plus attempts to set this value by working backward from a rule whose THEN statement assigns a value to the parameter.

**Bug** - A mistake in a computer program.

**CONSULT** - A PC Plus activity that starts a consultation with the knowledge base selected at the first PC Plus screen.

**Controller Assembly** - A complete electrical mechanism mounted in a cabinet for controlling the operation of a traffic control signal.
Controller Unit - The part of the controller assembly which performs the basic timing and logic functions (NEMA).

Coordination - The establishment of a definite timing relationship between adjacent traffic signals.

Cycle Length - The time required for one complete sequence of signal indications.

Detector - A device for indicating the presence or passage of vehicles or pedestrians (NEMA, 1975). This general term is usually supplemented with a modifier, i.e. loop detector, magnetic detector (probe) indicating type.

Detector Memory - The retention of an actuation for future utilization by the controller assembly.

DEVELOP - A PC Plus activity that starts a development session with the knowledge base selected at the first PC Plus screen.

Dilemma Zone - The portion of the roadway in advance of the intersection within which a driver can neither stop prior to the stopline nor clear the intersection before conflicting traffic proceeds.

EXPECT - A parameter property that specifies the possible values for a SINGLEVALUED or ASL-ALL parameter.

Forward Chaining - A search method in which PC Plus tries an antecedent rule each time it assigns a value to a parameter in the antecedent rule's IF statement.

EXTENDED CALL - A detector feature holds the call of a vehicle for a preset period of seconds.
Frame - The basic structure of a PC Plus knowledge base which collects information from a specific domain.

Full-Actuated Operation - The controller operates on continuously variable cycle lengths and all phases are in actuated mode.

Goal Parameter - The parameter whose values PC Plus searches for by testing rules and prompting the client (in a backward chaining knowledge base). These values provide the solution to the problem PC Plus is trying to solve.

HOW - A consultation command that provides and explanation of how EXACT reached a specific conclusion.

Inference Engine - The component of an expert system that applies the knowledge base facts to the user's information and infers a solution to the given problem.

Interval - A discrete portion of the signal cycle during which the signal indication remains unchanged.

Knowledge Engineer - The person who develops an expert system.

:LEFT - A formatting command that sets the left margin of the text to the integer that the developer specifies after the command.

:LINE - A formatting command that starts a new line. If followed by a number, the command advances that number of lines.

Locking Detection Memory - An optional feature in the controller unit whereby the all of a vehicle arriving on the red (or yellow) is remembered or held by the controller after the vehicle leaves the detection area until the green is given to that vehicle.
**Loop Detector** - A detector that senses a change in inductance of its inductive loop sensor by the passage or presence of a vehicle near the sensor. The loop could have a rectangular shape, diamond, or other shapes. Some agencies define a loop up to 20 ft. length as a short loop and a loop 60 ft. or longer as a long loop.

**Memory** - The mode of operation by which an actuation is held in the controller unit for future utilization.

**Minimum Green Interval** - The shortest green time of a phase. When this time is set into the controller unit, the green time shall be not less than that setting.

**Nonlocking Memory** - A mode of actuated-controller unit operation which does not require memory (NEMA).

**PARAMETER** - A structure that identifies a piece of information that PC Plus needs to arrive at a conclusion.

**PARAMETER VALUE** - A piece of information assigned to a parameter during a consultation to help EXACT reach a conclusion.

**Passage Time** - The time allowed for a vehicle to travel from the detection point in the roadway to the stopline. Unit Extension, unit interval, or preset gap are synonyms for this term.

**PC Plus** - Personal Consultant Plus (PC Plus) is an expert system rule-based shell made by Texas Instruments.

**Phase** - The portion of green time where the right-of-way is assigned to one or more traffic movements.
PREMISE - A rule's IF statement, which specifies one or more conditions to implement the actions listed in the THEN statement.

Presence - A detection operation when a vehicle occupies a loop, the detector shall be capable of maintaining a detection output for a minimum specified time.

Pulse - A detection output between 75 and 150 milliseconds shall be initiated when a vehicle enters the detection zone.

Probe - The sensor form that is commonly used with a magnetometer type of detector (NEMA).

PROMPT - A question shown on the screen during a consultation session.

Quadruple - A loop configuration that adds a longitudinal sawslot along the center of the rectangle, so that the wire can be installed in a figure-8 pattern. This design improves the sensitivity of detection.

:RIGHT - A formatting command that sets the right margin of the text to the integer that the developer specifies after the command.

Semi-Actuated Operation - Operation where only the minor street is operated in actuated mode.

Sensitivity - As it relates to a loop system the change in total induction of a system caused by a minimum vehicle at one loop, expressed as the percentage of the total induction.

TEXTAG - A special type of parameter with which the PC Plus user can specify a short name for a long section of text. The TEXTAG value (the short name) can be used as often as necessary without having to retype the long section of text.
THEN - A required rule property that expresses the actions taken if the condition or conditions in the rule’s IF statement.

Trace feature - A PC Plus facility that produces a written record of the flow of logic during a consultation. The developer can send the output to the screen, a printer, or a file.

TRAC OFF - A consultation command that turns off or suspends the Trace feature.

TRACE ON - A consultation command that turns on the Trace feature for the current consultation. This facility prints a record of the consultation logic.

Tracing - The Process of determining the value or values of a parameter.

TRANSLATION - A frame property that provides text to describe the purpose or content of the frame.

TRANSLATION - A parameter property with which the developer can provide an English phrase that describes the parameter. PC Plus uses this phrase in references to the parameter (in translating rules and in responding to WHY commands.)

Traffic Control - Regulation, Warning, and guidance of traffic for the purpose of improving the safety and efficiency of traffic flow.

TYPE - A parameter Property that tells PC Plus what kind of value the parameter can take. This property affects the way PC Plus traces the parameter, and it also determines the way PC Plus constructs a prompt.

Volume-Density Controller unit - A type of actuated controller unit which has added initial and gap-reduction timing features.

WHY - A consultation command that provides an explanation of why EXACT needs a specific response during a consultation.
YES/NO - A possible value of a parameter's TYPE property. A YES/NO parameter can have a value of either YES or NO.