A Thesis
Entitled

Study On Capacity Of Railroad Network And Airport Terminals For Upper Midwest Freight Corridor

by
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from Bureau of Transportation Statistics (BTS) website. Railroad crossing inventory
database was obtained from the Federal Railroad Administration (FRA). The BTS and
FRA data obtained were large and could not be used directly into the model algorithm.
Thus, selection criterion was developed to limit the railroad network and airports in the
study region.

The selected class I railroads and selected airports data were arranged in
appropriate format for proper application of the above- specified methodologies.
Application of methodologies to datasets identified the areas with excess capacity and
limited capacity (Potential bottlenecks) for railroads in study region. Track utilization
factor (TUF) in terms of usage to practical capacity was developed for segments of
railroad network. It was observed from the study that the average train speed is the
critical factor affecting the railroad capacity. The study also estimates the airport capacity
and showed the freight flow (tons per month), number of passenger and freight aircrafts
per hour served within each major intercity airports in the study region. It was observed
that most of the major airports in the upper Midwest freight corridor study region have
higher than 50 percent-unused capacities.
Acknowledgements

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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xi</td>
</tr>
<tr>
<td>Chapter 1 Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Overview</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Objectives</td>
<td>3</td>
</tr>
<tr>
<td>Chapter 2 Literature Review</td>
<td>5</td>
</tr>
<tr>
<td>2.1 Railroads in the U.S.</td>
<td>5</td>
</tr>
<tr>
<td>2.1.1 Railroad companies</td>
<td>5</td>
</tr>
<tr>
<td>2.1.2 Freight on Railroads</td>
<td>7</td>
</tr>
<tr>
<td>2.1.3 Class I freight railroads</td>
<td>9</td>
</tr>
<tr>
<td>2.1.4 Highway –Rail Freight</td>
<td>9</td>
</tr>
<tr>
<td>2.1.5 Benefits of using railroads</td>
<td>11</td>
</tr>
<tr>
<td>2.2 Importance of Railroad Capacity</td>
<td>12</td>
</tr>
</tbody>
</table>
2.2.1 Definitions of Railroad Capacity

2.2.2 Studies to Determine Railroad Capacity

2.3 Measures of Railroad Capacity

Theoretical Capacity

Practical Capacity

Used Capacity

Available Capacity

2.4 Parameters affecting Railroad Capacity

2.4.1 Plant Parameters

2.4.2 Traffic Parameters

2.4.3 Operating Parameters

2.4.4 Sensitivity Analysis

2.5 Introduction to Airport Terminals in the nation

2.5.1 Air freight

2.5.2 Benefits of Airport Terminals

2.6 Airport Capacity

2.6.1 Airside and Landside Capacity defined by FAA

2.6.2 Parameters Affecting Airport Capacity
2.6.3 Studies on Airport Capacity

2.7 Conclusions from literature Review

Chapter 3 Study Area

3.1 Identification of Railroads and Airport terminals in the Study region

Chapter 4 Database Development

4.1 Railroads data

4.1.1 Railroad link by link Database

4.1.2 Railroad crossing node Data

4.1.3 Processing of Railroad Data

4.1.4 Integrated Class I Railroad Network

4.1.5 Process of Linking databases to Integrated class I railroad network

4.1.6 Selected Railroad Network

4.2 Airport Terminals Data

4.2.1 Processing the Airport Terminal Data

4.2.2 Selection Criteria for Airports

Chapter 5 Methodology

5.1 Railroad capacity Algorithm

5.1.1 Railroad capacity Program
5.2 Airport Terminals Ultimate Capacity 64

5.2.1 Maximum Number of Passenger and Freight flights 68
within the intercity corridor

Chapter 6 Results and Discussions 70

6.1 Railroads 70

6.1.1 List of Some Significant Bottlenecks in the Study Region 73

6.1.2 Limitation of Railroad capacity Study 73

6.1.3 Effect of Parameters on Capacity 74

6.2 Airports 75

Chapter 7 Summary and Conclusions 82

Recommendations for Future Research 84

References 85

Appendix –A: Railroads 88

Appendix –B: Airports 97
## List of Tables

<p>| Table 2.1 | The U.S. Freight Railroad Statistics | 8 |
| Table 2.2 | Theoretical Railroad Capacities | 17 |
| Table 2.3 | U.S. Domestic Air Express Traffic | 27 |
| Table 4.1 | Example of Original Format of Rail (1:100,000 scale) Network Data | 38 |
| Table 4.2 | Example of Original Format of Rail (1:200,000) scale Network Data | 38 |
| Table 4.3 | Example of Original Format of Railroad Crossing Inventory Data | 38 |
| Table 4.4 | Format and attributes in BTS, FRA and Integrated railroad Network databases | 40 |
| Table 4.5 | Main Variables used for Capacity Estimations | 47 |
| Table 4.6 | Example of Format of Final Airport Terminals Database | 54 |
| Table 4.7 | List of Selected Airports for the Study | 57 |
| Table 4.8 | Hourly Arrivals and Departures and Freight Volumes of Selected Airports | 58 |
| Table 5.1 | Aircraft classification by type | 66 |</p>
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 6.1</td>
<td>Results of Railroad Capacity Model</td>
<td>72</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Railroad Segments Approaching Theoretical Capacity</td>
<td>74</td>
</tr>
<tr>
<td>Table 6.3</td>
<td>Airside Capacities for Selected Airports</td>
<td>78</td>
</tr>
<tr>
<td>Table 6.4</td>
<td>Number of Passenger aircrafts per hour</td>
<td>79</td>
</tr>
<tr>
<td>Table 6.5</td>
<td>Number of Freight aircrafts per hour.</td>
<td>80</td>
</tr>
<tr>
<td>Table 6.6</td>
<td>Freight volume (Tons/month)</td>
<td>81</td>
</tr>
</tbody>
</table>
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Type of freight carried by class I railroads</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>The Intermodal growth of US freight Railroads</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>Freight Market Share Trend</td>
<td>11</td>
</tr>
<tr>
<td>2.4</td>
<td>The types of Capacities of the Subdivisions</td>
<td>16</td>
</tr>
<tr>
<td>2.5</td>
<td>Effect of signal spacing on capacity</td>
<td>23</td>
</tr>
<tr>
<td>2.6</td>
<td>Effect of Siding spacing on capacity</td>
<td>23</td>
</tr>
<tr>
<td>2.7</td>
<td>Effect of Length of Segment on capacity</td>
<td>24</td>
</tr>
<tr>
<td>2.8</td>
<td>Effect of Speed on capacity</td>
<td>24</td>
</tr>
<tr>
<td>2.9</td>
<td>Airport classifications</td>
<td>25</td>
</tr>
<tr>
<td>2.10</td>
<td>Graphical Runway Capacity</td>
<td>32</td>
</tr>
<tr>
<td>3.1</td>
<td>Railroads in the study region</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>Airport Terminals in the Study Area</td>
<td>36</td>
</tr>
<tr>
<td>4.1</td>
<td>Databases for developing Integrated Class I Railroad Network</td>
<td>39</td>
</tr>
<tr>
<td>4.2</td>
<td>Final railroad base map network</td>
<td>42</td>
</tr>
<tr>
<td>4.3</td>
<td>Conceptual Development of Class I Railroads</td>
<td>44</td>
</tr>
</tbody>
</table>
Figure 4.4  The Process of Segmentation 45

Figure 4.5  Selected Railroad Network for Capacity Analysis 46

Figure 4.6  Flow of Activities to generate Final Database for Class I Railroad Network 48

Figure 4.7  Monthly arrivals (aircrafts/hour) for Chicago O’Hare International Airport (ORD). 50

Figure 4.8  Monthly departures (aircrafts/hour) for Chicago O’Hare International Airport (ORD). 50

Figure 4.9  Maximum frequencies of Arrivals 51

Figure 4.10  Maximum frequencies of Departures 51

Figure 4.11  Flow diagram Showing the Joining of Airports Database 53

Figure 4.12  Selected Airport Terminals in the Upper Midwest Freight Corridor Study Region. 56

Figure 5.1  Flow of Activities in Railroad Capacity Algorithm 63

Figure 5.2  Flow diagram showing Railroad Capacity Model Steps 64

Figure 5.3  Flow chart showing the Methodologies used for Airport Capacity Study 67

Figure 6.1  Track Utilization Factor for Railroad Segments 71

Figure 6.2  Graph showing relationship between Delay slope and Average Speed 75
Chapter 1

Introduction

1.1 Overview

One of the most important elements in the transportation and transportation systems is Freight. The freight is carried by truck, rail, water and air. The multimodal freight transportation reduces the costs of congestion and thrives to maintain transportation connections among ports, manufacturing/distribution centers, agricultural areas, and tourist locations, thus having a direct impact on the economy and quality of life.

In this modern world the demand to move goods from place to place is increasing drastically, resulting in significant increase in freight movements in the future [1]. Hence, a sound multimodal transportation system is needed to vitalize the economy and facilitate the desired growth.

The best way to express corridor multimodal transportation system is through the capacity of each segment traveled by each mode in the network. There might be some areas in the corridor having either excess (available) capacity or limited capacity (bottlenecks) i.e. the current capacity is not able to meet the existing travel demands. These potential bottlenecks work as major obstacles for freight movements.
Therefore there is a need to calculate multimodal capacity and identify the areas with and excess capacity. Thus an understanding of the freight travel demand and the facility capacity will provide proper planning for the corridor.

At present, of all multimodal transports, highways carry most of the freight, due to which the highways are experiencing rigorous congestion problem. Thus the highways will not be able to meet the future freight demand. Therefore to reduce congestion and meet the future freight demands the two immediate solutions are: (1) Either construct or expand highways which involve lot of time, money and resources or (2) To make utilize of the existing multimodes such as railroads, airports and waterways for transporting freight.

The current research concentrates on the capacity aspects of two major multimodal transports: Rail and Air in the Upper Midwest freight corridor study region.

The upper Midwest freight corridor is selected as the study region because it is critical corridor connecting all the Midwest states, intermodal terminals and ports. This corridor plays an important role in the nation’s economy and is responsible for transporting freight throughout the corridor and to border country Canada.

Railroads play an important role in freight transportation since they are cost effective as compared to other modes for transporting bulk and long distance commodities. Each railroad link in the study region is responsible for carrying freight up to a maximum of 100 million gross tons and connects most of the intermodal terminals.

The airports are cost effective in transporting long distance, high value and perishable goods. The airport terminals in the study region carry a maximum monthly tonnage of 142,212 tons.
The Federal Railroad Administration (FRA) has defined the ultimate capacity of a railroad system component under ideal conditions as the engineering capacity [2], which means, “For Railroads, a fixed capacity is assumed for a given route segment based on one or two simple variables such as signal type and number of tracks.”

The Federal Aviation Administration (FAA) defines airside capacity as the maximum number of aircraft operations (arrivals, departures) that can take place in an hour [1].

There is a need to understand how the various parameters constraint railroad and airport capacity.

1.2 Objectives

The objectives of this research are:

- To study the parameters that impacts the railroad capacity.
- To select a railroad network from the upper Midwest freight rail corridor based on segmentation.
- To apply the railroad capacity model and estimate capacity of individual segments in the selected network.
- To understand the effect of changes in capacity parameters on the track capacity.
- To identify the areas of either limited capacity (potential bottlenecks), or areas of over capacity that could meet the increasing traffic demand.
- To select important airport terminals for capacity analysis from the corridor based on elimination criteria.
• To estimate the ultimate capacities for selected airport terminals.

• To find maximum number of passenger and freight aircrafts served within each intercity corridor and freight carried within the intercity corridor.

The research also aims to provide a comprehensive approach to railroad and air corridor capacity analysis for freight movements. This multimodal capacity approach can be used for regional planning.
Chapter 2

Literature Review

2.1 Railroads in the U.S.

Railroads were introduced in England in the seventeenth century to reduce friction in moving heavily loaded wheeled vehicles. Colonel John Stevens [3], father of railways introduced the concept of constructing a railroad in the United States, in 1812. The earliest railroads constructed were used for transporting freight. In the year 1837, due to the industrial and commercial depression, railroad construction slowed down. The interest to build railroads began again with the completion of the western railroads of Massachusetts in the year 1843. This railroad transported agricultural products and other commodities for long distances at low cost. Since then every year the number of railway systems grew exponentially. Various companies began to cooperate with one another, to both maximize profits and minimize the expenditures. This continued throughout the rest of the nineteenth century. As a result, the railroad industry turned out to be the major building block for nation’s economic growth.

2.1.1 Railroad Companies

In the year 1851, the federal government issued land grants to Illinois to construct the Illinois Central railroad. Through this the government set a path for the growth of railroad companies in the nation.
The Union Pacific Railroad Company [4] started building from the east, while the Central Pacific began from the west. All large corporations built several more transcontinental railroads before the end of the century. Some of the important facts about railroad companies in the U.S. are listed below.

- Burlington Northern Santa Fe is one of the largest rail networks in North America, with operating distance of roughly 33,500 route miles in 28 states and moves more intermodal traffic than any other railroad system in the world. BNSF is the largest grain-hauling railroad in the United States.
- Conrail provides freight service in Detroit, New Jersey and Philadelphia. It operates 359.4 miles in Detroit, 471.4 miles in north half of New Jersey and 372.7 miles in Philadelphia/South Jersey.
- CSX Transportation operates around 22,700 route-miles in 23 states. It is the father of numerous subsidiaries that serve freight transportation across the world. It is the largest rail network in eastern United States.
- Norfolk Southern Corporation is the major freight railroad that operates in 21 states in the east and Midwest regions in U.S. It connects more than 220 regional railroads.
- Union Pacific Corporation is one of the America's leading transportation companies. It is the principal operating company. It operates over 33,586 route miles in 23 states across the western two-thirds of the United States with 153,272 freight cars, and moving 8.92 million carloads of materials each year.
Wisconsin Central is a regional North American rail system in Wisconsin, the Upper Peninsula of Michigan, Northeastern Illinois, Eastern Minnesota and Ontario.

Most of these railroad companies are well known for transporting freight.

2.1.2 Freight on Railroads

U.S. freight railroads [5] serve nearly every sector of the nation’s economy. They move forty two percent of the nations freight measured in ton-miles. Every year they contribute billions of dollars to the economy through investments, wages and taxes. Thus, the freight railroads are considered to be noteworthy for the global competitiveness of the nation.

The U.S. freight railroad statistics [6] given by Association of American Railroads (AAR) for the year 2001 and 2002 are specified in the Table 2.1. Table 2.1 gives the operating employment, traffic and financial statistics. From the traffic statistics it can be seen that 2.12 billion tons of freight is originated through the U.S. freight railroads annually. The financial statistics show that the annual revenue generated by the 552 freight railroads in the year 2002 was $36.9 billions.

In Table 2.1, ‘Miles of Road’ is the aggregate length of roadway, excluding yard tracks and sidings. ‘Miles of Road Operated Less Track age Rights’ means it eliminates double counting caused by more than one railroad operating the same track. Excluding track age-rights, U.S. Class I railroads operate 141,961 miles which include 141,391 in
the United States and additional 570 miles operated by the Canadian railroads operating in the U.S.

### Table 2.1 U.S. Freight Railroad Statistics

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Railroads</td>
<td>571</td>
<td>552</td>
</tr>
<tr>
<td><strong>Operating Statistics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miles of Road Operated Less Trackage Rights</td>
<td>143,361</td>
<td>141,961</td>
</tr>
<tr>
<td>Miles of Road Operated in the U.S.</td>
<td>171,430</td>
<td>170,348</td>
</tr>
<tr>
<td>Freight Cars in Service, U.S. Railroad Owned*</td>
<td>625,330</td>
<td>608,341</td>
</tr>
<tr>
<td>Freight Cars in Service, All U.S. Owners*</td>
<td>1,314,136</td>
<td>1,299,670</td>
</tr>
<tr>
<td><strong>Employment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Employees</td>
<td>184,369</td>
<td>177,060</td>
</tr>
<tr>
<td>Average Wages</td>
<td>$56,878</td>
<td>$58,421</td>
</tr>
<tr>
<td>Average Compensation Including Benefits</td>
<td>$77,831</td>
<td>$80,319</td>
</tr>
<tr>
<td><strong>Traffic</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Carloads Originated (million)</strong></td>
<td>31.95</td>
<td>32.43</td>
</tr>
<tr>
<td>Tons Originated (billion)</td>
<td>2.12</td>
<td>2.15</td>
</tr>
<tr>
<td>Ton-miles (trillion)</td>
<td>1.56</td>
<td>1.56</td>
</tr>
<tr>
<td><strong>Financial</strong></td>
<td></td>
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</tr>
<tr>
<td>Freight Revenue (billion)</td>
<td>$36.60</td>
<td>$36.90</td>
</tr>
</tbody>
</table>

Source: Association of American Railroads, 2002

*U.S. owned only, excludes Canadian-owned railroads operating in the U.S.

**Carloads shown here uses the Surface Transportation Board's Freight Commodity Statistics and the AAR's Profiles of U.S. railroads survey as sources, and will not match the total carloads reported in railroads and States, which uses the Carload Waybill Sample as a source.
2.1.3 Class I Freight Railroads

Class I railroads [7] are U.S. line haul freight railroads with operating revenue in excess of $272.0 million. The Class I railroads in 2002 are: The Burlington Northern and Santa Fe Railroad, CSX Transportation, Grand Trunk Corporation, Kansas City Southern Railway, Norfolk Southern Combined Railroad Subsidiaries, Soo Line Railroad, and Union Pacific Railroad.

Figure 2.1 shows the commodities (expressed in percent of the total ton miles) carried by class I railroads. It is observed from the figure that the commodities carried are coal (40 percent), intermodal traffic (trailers and containers on flat cars 16 percent), farm products (predominantly grain and soybeans 9 percent), and chemical products (9 percent).

Figure 2.2 shows the intermodal growth of US freight railroads till the year 2002. The fastest growing section of rail traffic is the intermodal traffic. It is clear from Figure 2.2 that the number of trailers and container loadings increased from 3.4 million units in 1980 to 9.3 million units in year 2002.

2.1.4 Highway vs. Rail Freight

The freight market share trends from 1960 to 1998 show that trucks and rails account for 64 percent of the nation's domestic freight volume [8], while pipelines and waterways account for the rest. During this period, rail freight decreased slightly from 38 percent to 37 percent of volume, whereas the truck volumes increased from 19 percent to 28 percent. Figure 2.3 shows the freight market share trends from the year 1960 to 1998 for multimodal transport.
Figure 2.1 Type of Freight Carried by Class I Railroads

Source: Association of American Railroads

Figure 2.2 The Intermodal Growth of US Freight Railroads

Source: Association of American Railroads, “Railroad Facts”
Figure 2.3 Freight Market Share Trend

Source: Calculated from US Department of Transportation Data

2.1.5 Benefits of using Railroads

Today, the rail industry has proven to be more environmentally sound than a number of other modes of transportation. According to the American Society of Mechanical Engineers [9] 2.5 million fewer tons of carbon dioxide would be emitted into the air annually if 10 percent of intercity freight now moving over-the-road were switched to rail. From the freight point of view since 20 years, the claims for damaged cargo fell to 58 percent while cargo volumes increased by 50 percent. The railroads and trucks carry approximately the same number of ton-miles of hazardous materials. It is also specified by the Bureau of Labor Statistics that the accident rate has reduced in the
railroad industry by 70 percent since 1980, which proves that railroads are safer than any other modes of transportation.

The literature cited until now gives a general introduction on the railroads in the nation. The following sections deal with the capacity of railroads, which is the prime aspect in this study.

2.2 Importance of Railroad Capacity

Rail is the only commercial transportation mode available to many agricultural shippers [7] who are not located near markets or waterway transportation, thus emphasizing the need for railroad service and capacity for the agricultural industry in the U.S. Capacity has been a significant issue in the railroad industry [10] as it helps to determine the amount of traffic that can be moved and the degree of service and reliability.

2.2.1 Definitions of Railroad Capacity

The Federal Railroad Administration (FRA) has defined the ultimate capacity of a railway system component under ideal conditions as the engineering capacity [2], i.e., “For Railroads, a fixed capacity is assumed for a given route segment based on one or two simple variables such as signal type and number of tracks.”

In the Parametric rail capacity model, Harald Krueger [10] defined railroad capacity as “The highest volume (trains per day) that can be moved over a subdivision (plant) under a specified schedule and operating plan (traffic and operations) while not exceeding a defined threshold (over-the-road-time).”
2.2.2 Studies to Determine Railroad Capacity

Over the past 30 years numerous studies have been conducted on railroad capacity estimations. Some of them are discussed below:

A study conducted by Livio Florio and Lorenzo Mussone [11] on validity of using analytical methods for calculating capacity of railway lines and stations expresses capacity at any point as the maximum number of trains that can occupy a line or a station in a given time interval. In this study statistical distributions for arrival of trains at a singular point of a certain line and the average time distance calculations are performed. This interprets delay as a function of probability density function, Capacity is then estimated from the delay function. The result from the study includes the calculations of the real occupation time of the track, which includes the entrance and exit times, and the time delay caused by the line and node interference due to possible causes of deviation from the regular timetable. The method used in the study can also be used to other transportation systems.

A study conducted by Li Zhou [12] on computational methods to calculate the rail transport capacity of railroad sections and joint terminals conclude the railroad capacity as the converted ton-kilometer in carrying passenger and goods each day and not the number of trains passing each day. The two main reasons for such a conclusion include:

(1) Different trains travel different transport distances

(2) Different passenger and freight trains have different tractive number

The capacity of a railroad section refers to maximum number of freight trains passing through the section in average minimum time interval along with passenger trains
according to number and type of locomotive stock and train crew. For joint terminal, rail transport capacity means converted freight mileage (i.e., the product of converted passenger and freight traffic and length of the section) implemented by departure and passing trains in the joint terminal. Joint terminal considers three aspects (1) the line linked up with the joint terminal (2) the line in the joint terminal and (3) station in the joint terminal. The carrying capacity distributed by joint terminal should be less than capacity in section of various lines. The important asset of this study is in its help towards improvement of transportation layout. This study helps in finding the weak link and provides reasonable measurement for development and planning. The main drawback of the study is that it takes running train groups as stochastic (assumed) things.

A study conducted by The Tennessee Valley Authority (TVA) and the Center for Business and Economic Research (CBER) [13] on “The Incremental Cost of Transportation Capacity in Freight Railroading for Snake River Basin” provides a general description of a model to estimate rail capacity and detailed railroad construction costs. The railroad capacity depends on both space and time and is measured by counting the number of trains that can be moved over the network link in a specific time period. The study identifies a section of railroad segment and collects information about railroad configuration and the number of trains moving on the railroad, and then relates observed trains to line characteristics. Capacity is observed as a function of track configuration and the quality of track components. The estimation of results from the study gives correlation between observed rail traffic and those variables used to represent the quality and configuration of track structures.
A study conducted by Robert H. Leilich [14] on “Application of Simulation Models in Capacity Constrained Rail Corridors” shows how rail simulation models are used to find the capacity of constrained rail traffic corridors. This is useful in helping the railroad company run more trains by providing early warning for lines nearing capacity. These simulation models are performed hundreds of times to define statistical relationships between train configuration, signalization and operating practices. It is observed that a linear relationship exists between number of trains per day and average delay per train, signal spacing, sidings, crossover spacing, train stop time and speed cause delay. The advantage of simulation models in railroad industry is to give a better understanding of operating relationships, which affect the railroad capacity. The simulation models act as a cost effective decision tool, which improve service performance and reliability.

In a study on “Parametric Modeling in Rail Capacity Planning” Krueger [10] develops a model in windows 95-based program to measure the theoretical, practical, used and available track capacity. The tool emphasizes more on practical track capacity. It is dependent on plant, traffic and operating parameters. The practical capacity equation was best expressed as the relationship between train delay and traffic volume. Numerous simulations were performed considering each parameter individually and taking others as constants. Through these relationships with parameters and train delay, a practical capacity curve was defined for a subdivision under specified conditions. The available capacity, which is the difference between used and practical capacity, was used as an indication for track utilization. The model developed in this study acts as an effective decision support tool for capacity management. It highlights on the parameters that
reflect the real world. It is easy to use and provides capacity for any number of subdivisions. The only limitation of this model is that it takes each parameter individually and performs numerous simulations, which consumes a lot of time. Figure 2.4 shows the graph displaying the used, practical and theoretical capacities for three sub-divisions.

Figure 2.4 Types of Capacities of the Subdivisions

Source: Parametric Analysis of Railway Line Capacity
2.3 Measures of Railroad Capacity

The various measures [10] of railroad capacity are:

1. Theoretical or Physical Capacity
2. Practical Capacity
3. Used Capacity
4. Available Capacity

The measures are defined and summarized below:

2.3.1 Theoretical or Physical Capacity
   It is the maximum upper limit of capacity. It assumes all trains are the same, with equal priority and evenly spaced throughout the day. It neglects the effects of traffic and operational parameters that occur in reality. The theoretical capacities specified by FRA are shown in Table 2.2.

Table 2.2 Theoretical Railroad Capacities

<table>
<thead>
<tr>
<th>Number of Tracks</th>
<th>Theoretical Capacity (Trains/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Track</td>
<td>60</td>
</tr>
<tr>
<td>Double Track</td>
<td>160</td>
</tr>
</tbody>
</table>

Source: Federal Railroad Administration

2.3.2 Practical Capacity
   Practical capacity is the practical limit of traffic volume that can be moved on a railroad, not exceeding the defined performance threshold. The performance threshold is defined as the upper limit of maximum trip time for priority traffic.
2.3.3 Used Capacity

Used capacity is defined as the actual number of trains passing over the section. It is an actual representation of traffic and operational changes that occur on the railroad.

2.3.4 Available Capacity

Available capacity is defined as the difference between used and practical capacity. It gives an indication of the additional traffic volume that could be accommodated not exceeding the predefined performance threshold.

Practical capacity is one of the most important measures of track capacity because it considers the plant, traffic and operating parameters for capacity estimations.

2.4 Parameters Affecting Railroad Capacity

The three main parameters [10] affecting railroad capacity are:

1. Plant Parameters
2. Traffic Parameters
3. Operating Parameters

The three parameters are described below

2.4.1 Plant Parameters

Length of the Subdivision: The distance in miles between the starting and end points of the subdivision. As the length of the subdivision increases so does the travel time of trains. Hence the capacity decreases.
Meet Pass Planning Point Spacing (MPPPS): The average spacing of locations used to meet or overtake trains. These locations are necessary for the operations of bi-directional, mixed priority and speed traffic. It is calculated as given in equation 2.1

\[
MPPS = \frac{\text{Length of Subdivision (miles)}}{(\text{Number of MPPP} +1)} \quad \text{---2.1}
\]

Percent Double Track (% DT): Double or multiple track segments have a significant impact on a track’s ability to move trains. Capacity of a line increases quickly with properly spaced sections of double track because it allows for running meets and more than one train in a segment. It is calculated as given in equation 2.2

\[
\% \text{ DT} = \left( \frac{\text{Miles of Double Track}}{\text{Length of Subdivision}} \right) \times 100 \quad \text{---2.2}
\]

2.4.2 Traffic Parameters

Traffic Peaking Factor (TPF): The concentration of traffic within a short time period is often called as peaking. It has a significant impact on capacity because it can result in traffic levels higher than the section could reliably sustain. It is calculated as given in equation 2.3

\[
TPF = \frac{\text{Maximum Trains in 4 hours}}{\text{Average Trains in 4 hours}} \quad \text{---2.3}
\]

Priority Probability (PP): The priorities of trains play a vital role in deciding which trains will experience delay. Train priorities decrease capacity because high priority trains are given preference over lower priority trains, which result in increased delays. The four train priorities considered are passenger, express, freight and unit. Each train is assigned a priority associated with their speed class. It is given in equation 2.4
\[ PP = \frac{1}{T} \sum_{i=2}^{N} \left( \frac{C_i}{(T-1)} \right) \times \sum_{j=1}^{i-1} C_j \]  \quad \text{----2.4}

Where,

\[ N = \text{Number of priority classes (4 max)} \]
\[ T = \text{Daily number of trains} \]
\[ C_i, C_j = \text{Number of ith, jth priority class trains} \]

Speed Ratio (SR): The speed differential between trains can significantly increase delay on a subdivision. The speed ratio is based on the following assumptions

a) It is non-directional because train speeds affect both opposing and overtaking traffic.

b) The slowest and fastest trains are assumed to be on-line at the same time

The speed ratio is given in equation 2.5

\[ SR = \text{Fastest Train Speed} / \text{Slowest Train Speed} \]  \quad \text{-----2.5}

Average operating speed: A significant parameter affecting capacity is average train speed. Higher speeds reduce both delay and transit time. This is because faster trains spend less time traveling a given distance, occupy the track for less time and move between MPPP’s. Faster trains will spend less time waiting for conflicts to clear since opposing trains are faster as well.
2.4.3 Operating Parameters

Track Outages (TO’s): Track outages are planned and unplanned events that take a track out of service. This affects the capacity of a line because it directly reduces the number of hours available in the day to move trains. It is given in equation 2.6

\[
\text{TO’s} = \frac{\text{Total Duration of Outages}}{\sum_{i=1}^{n} \frac{1}{n_T d_i}}
\]  ----2.6

Where:

\( n_T = \) total number of outages per day
\( d_i = \) duration of each outage (hrs)

Temporary Slow Orders (TSO’s): Like track outages, TSO’s also have an impact on capacity. TSO’s generate two types of delays one is the time loss due to operating at slower than normal speed and the other is the acceleration and deceleration time. It is calculated as given by equations 2.8, 2.9, 2.10.

\[
\text{TSO’s} = \text{Vtime} + \text{Traveltime}
\]  ----2.8

\[
\text{Vtime} = \left( \frac{V_m K - \text{TSOSpeed}}{A} \right) + \left( \frac{V_m K - \text{TSOSpeed}}{D} \right)
\]  ---- 2.9

\[
\text{Travel Time} = \left( \frac{L}{\text{TSO Speed}} + \frac{L}{V_m K} \right) \times 60
\]  --- 2.10

Where:

\( V_m = \) maximum freight speed (60mph)
\( K = \% \) of time running at max speed (85%)
A = acceleration rate (20 mph/min)
D = deceleration rate (30mph/min)
L = length of TSO + average train length

Train stop time (TST): This parameter accounts for the amount of time trains spend stopped on line doing work. It is a delay that directly increases the amount of time a train takes to traverse a subdivision. This time is expressed in hours.

Maximum Trip Time Threshold (MTTT): This parameter represents the maximum time spent by priority trains on the track. It is expressed in hours and is the critical factor, which, in combination with the other plant, traffic and operating parameters, is used to calculate the practical capacity of a subdivision.

2.4.4 Sensitivity Analysis

To show in detail how each parameter has effect on capacity sensitivity analysis is conducted. The main parameters considered for sensitivity analysis are Signal spacing, Siding spacing, Speed, Length of the segment. Taking each parameter for analysis and considering all the other parameters as constant capacity analysis is performed. By changing the value of the parameter the effect of it on the capacity is observed. The Figures 2.5 to 2.8 shows the effect of each parameter on capacity for single track and double track.
Signal Spacing:

![Signal Spacing Chart](chart1)

**Figure 2.5 Effect of signal spacing on capacity**

Siding Spacing:

![Siding Spacing Chart](chart2)

**Figure 2.6 Effect of Siding spacing on Capacity**
Length:

Figure 2.7 Effect of Length of Segment on Capacity

Speed:

Figure 2.8 Effect of Speed on Capacity

Observing the effect of the parameters on capacity, the operating speed is the main parameter that influences the capacity it is observed high operating speeds result in very high capacities.
2.5 Introduction to Airport Terminals in the Nation

The United States Airport terminals are one of the prominent airport systems in the world. Airports act as a medium for moving passengers and cargo. It plays a vital role in transporting commerce and national defense. The nation’s economic growth depends upon the U.S. airport industry [15].

According to the Federal Aviation Administration (FAA), there are approximately 19,300 airports in the United States, of which 28% are public facilities, usually operated by a state or local government. Figure 2.9 shows the classification of number of airports in U.S.

Figure 2.9 Airport classifications
Source: The Economic Impact of U.S. Airports 2002
Airports in United States contribute $507 billion each year to total economic activity. Over 1.9 million passengers travel and over 38,000 tons of cargo goes through U.S. airports for business and leisure each day. According to the Economic impacts on U.S. Airports report in 2002, air cargo is an important element for the economy of the nation. The U.S. cargo market has grown significantly during the past ten years and is expected to grow at the rate of 5.3% per year by the end of the year 2011.

2.5.1 Air freight

U.S. Domestic Air Freight and Express Industry Study [15] in the year 2002 concluded that the overall U.S. airfreight and express industry revenues totaled $27.3 billion. The mail representing 17% of the total cargo-ton-mile generated revenues up to $431 million. Air Cargo Management Group (ACMG) predicts that the world’s freighter fleet will grow to over 3,500 units through 2022, despite the fact that the global freighter fleet has remained essentially constant at 1,600 units since 2000. Table 2.3 shows that the daily volume in the U.S. domestic express market now stands at 6.675 million shipments per day.

2.5.2 Benefits of Airport Terminals

Airports provide significant transportation benefits and are the necessary means of connecting communities to world markets [15]. The most valuable benefit using air transportation is that it saves time and cost. The general benefits include standards of safety, comfort and convenience. From the economic point of view, U.S. airports contribute nearly $507 billion revenue each year in total for nation’s economic activity.
The total jobs related to airports translate into earnings and produce annual revenue of $190.2 billion to the nation.

In tax benefits, U.S. airports generate $33.5 billion in local, state and federal taxes. For the economic activity to continue to accommodate the existing and future freight and passenger demand there should be sufficient airport capacity.

Table 2.3 U.S. Domestic Air Express Traffic

<table>
<thead>
<tr>
<th>Air Express Company</th>
<th>2002 Daily Volume</th>
<th>Market share</th>
</tr>
</thead>
<tbody>
<tr>
<td>FedEx (12/02-2/03)</td>
<td>2,828,000</td>
<td>42.40%</td>
</tr>
<tr>
<td>United Parcel Service</td>
<td>2,252,000</td>
<td>33.70%</td>
</tr>
<tr>
<td>Airborne Express</td>
<td>1,243,900</td>
<td>18.60%</td>
</tr>
<tr>
<td>USPS Express Mail</td>
<td>240,400</td>
<td>3.60%</td>
</tr>
<tr>
<td>DHL</td>
<td>61,000</td>
<td>0.90%</td>
</tr>
<tr>
<td>Other (incl. BAX Global and Emery)</td>
<td>50,000</td>
<td>0.80%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>6,675,300</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: ACMG market research, as described in U.S., Domestic Air Freight and Express Industry Annual Study 2003
2.6 Airport Capacity

An Airport capacity is divided in two parts [1]: (1) Airside (2) Landside. The runways, taxiways and air traffic control systems define airside capacity while the aircraft parking positions and gates, terminal buildings, baggage service, access of roadways and automobile parking structures define the landside capacity.

The Landside capacity refers to the capability of the airport landside facilities and services to accommodate passengers, air cargo, ground access vehicles and aircrafts. The landside capacity is mainly used to estimate the passenger capacity.

2.6.1 Airside and Landside Capacity Defined by Federal Aviation Administration

Federal Aviation Administration defined Airside capacity as the maximum number of aircraft operations (arrivals, departures) that can take place in an hour.

Service volume is the principal indicator of landside capacity, which is the number of passengers that can be accommodated by a functional component or group of components in a particular time period relative to a particular demand at a given service level.

2.6.2 Parameters Affecting Airport Capacity

The parameters affecting airside capacity [1] are:

- Air craft configuration and number of runways, taxiways and aprons
- Aircraft size, speed, ground maneuverability
- Environmental effects (Visibility, winds and weather)
- Runway surface conditions
• Noise abatement requirements, Operating strategies for runway and air traffic control rules

Of all the parameters, runways are the main ones affecting airside capacity.

The parameters affecting landside capacity are:

• Aircraft parking position and gate
• Passenger waiting area
• Pass Terminal circulation (stairs, corridors)
• Terminal curb, parking area
• Ground access, baggage claim, customs and immigration and connecting passenger transfer

Runway capacity is divided in two parts: (1) practical capacity corresponding to a tolerable level of average delay and, (2) ultimate capacity defined as the maximum number of aircrafts that can be handled during a given period under conditions of continuous demand.

For the study purpose only ultimate runway capacity is estimated. The maximum runway capacity is reached when total runway occupancy time is equal to time headway between landing aircraft.

2.6.3 Studies on Airport Capacity

Federal Aviation Administration (FAA) specifies a graphical approach [16] for estimating airport capacity. According to FAA the main means to estimate capacity is through runways. FAA defines airport capacity as the maximum number of aircraft operations (arrivals, departures) that can take place in an hour.
The methodology used in this study first finds data on the payload of the aircrafts, number of arrivals and departures, and number of exit way locations. This data will be used to calculate the mix index, which is the sum of the percent of large aircrafts (12,500lb to 300,000) and three times percent of heavy aircrafts (greater than 300,000lb), percent arrivals at each airport. Hourly capacities are found by matching the mix index and percent arrivals at each airport. The ultimate capacity is obtained by multiplying the hourly capacity with number of runways at each airport as shown in Figure 2.10.

The advantage of using this methodology is in its feasible approach and use of lesser data parameters.

The study conducted by Noritake and Kimura (1993) for estimating airport capacity [17] is based on a simple mathematical formula. This study considers runways as the main means for estimating airport capacity.

The methodology of this study is based on the runway occupancy time during arrival and departure. The mathematical formula used in calculating the ultimate capacity of the runway is given in equation 2.11.

\[ C = \frac{7200}{(t_a+t_d)} \]  \[ \text{---2.11} \]

Where,

- \( C \) = runway capacity in terms of number of aircrafts/hour
- \( t_a \) = runway occupancy time of arriving aircraft (65 seconds assumed)
- \( t_d \) = runway occupancy time of departing aircraft (60 seconds assumed)

The ultimate capacity is then multiplied with number of runways in the airport to give the ultimate capacity of airport. The airport capacity in this study is expressed in
terms of aircrafts per hour. The study uses only three parameters for estimating the
capacity. The airport capacity can also be used to find number of passenger and freight
aircrafts served within intercity corridor.

It can be concluded from the studies that runways act as the backbone for airport
capacity estimations.
Exit Factor E

To determine the exit factor E:

1. Determine exit range for appropriate mix index from table below.
2. For arrival runways, determine the average number of exits (N) which are:
   (a) With in appropriate exit range, and (b) departed by at least 750 feet
3. If N is 4 or more, Exit factor = 1.00
4. If N is less than 4, determine exit factor from table below for appropriate mix index and percent arrivals

<table>
<thead>
<tr>
<th>Mix Index (C+3D)</th>
<th>Exit Range (Feet from threshold)</th>
<th>40% Arrivals</th>
<th>50% Arrivals</th>
<th>60% Arrivals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N=0</td>
<td>N=1</td>
<td>N=2 to 3</td>
</tr>
<tr>
<td>0 to 20</td>
<td>2000 to 4000</td>
<td>0.72</td>
<td>0.87</td>
<td>0.94</td>
</tr>
<tr>
<td>21 to 50</td>
<td>3000 to 5500</td>
<td>0.79</td>
<td>0.86</td>
<td>0.94</td>
</tr>
<tr>
<td>51 to 80</td>
<td>3500 to 6500</td>
<td>0.79</td>
<td>0.86</td>
<td>0.92</td>
</tr>
<tr>
<td>81 to 120</td>
<td>5000 to 7000</td>
<td>0.82</td>
<td>0.89</td>
<td>0.93</td>
</tr>
<tr>
<td>121 to 180</td>
<td>5500 to 7500</td>
<td>0.86</td>
<td>0.94</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Figure 2.10 Graphical Runway Capacities
Source: Federal Aviation Administration
2.7 Conclusions from Literature Review

- Of all the capacities the practical railroad capacity is an important measure to express the track condition.

- The plant, traffic and operating parameters play crucial role in estimating the railroad capacity.

- The effect of the parameters on the network can be significantly observed only by dividing network into subdivisions.

- Railroad capacity is a function of delay and expressed in terms of number of trains per day.

- The airport capacity is divided into two parts, one is the airside capacity and the other is the landside capacity. Although the landside capacity is an important aspect in air transportation, it is entirely related to passengers and airport operators who manage the landside capacity. Therefore landside capacity is beyond the scope of study.

- The airport terminal capacity depends heavily on the runways, which is considered to be the most important parameter for capacity estimations. Airport capacity is expressed in terms of aircrafts per hour.

The present research concentrates on estimating the railroad capacity considering the key parameters affecting the capacity, and identification of the potential bottlenecks for selected railroad network. The research also concentrates on selection of major airports and estimation of airport ultimate capacity. It also gives the number of passenger aircrafts, freight aircrafts and freight flows within the intercity major airports.
Chapter 3

Study Area

The upper Midwest freight corridor region was considered for this research. The region is defined by I-94/I-90/I-80 corridor connecting all the upper Midwest states Ohio, Michigan, Ontario, Indiana, Illinois, Wisconsin, Iowa and Minnesota [18]. The present study does not include Manitoba and Ontario. The study region also includes the border traffic from Canada. The region for analysis includes the major modes of transportation and places that generate and or receive goods. The corridor plays an important role in transporting freight. The region is responsible for about forty percent of nation’s international trade in terms of dollars [19]. The corridor contribute major portion to nations economy through revenue generated from freight.

3.1 Identification of Railroads and Airport Terminals in the Study region

There are approximately 195,182 railroad links in the upper Midwest freight corridor region operating up to 58,426 track miles. The railroads in the study region are classified into class I, regional and local railroads. Figure 3.1 shows the railroad classes of rail (1:100,000scale) network in the study region. The freight carried by the railroads is expressed in terms of Density (MGTM/MI). The density of the line ranges from 0-7. The value 0 means it is an abandoned line and 7 means that the line can carry freight more
than 100 million gross tons. The airport terminals listed in the study area are roughly about 103. Figure 3.2 shows the airport terminals in the study region. The most important parameter used in the capacity estimations is the runway. There are about 1430 runways in the study region.

The railroads and airport terminals serve the intermodal terminals (where the goods are transferred from one mode to another) in the corridor.

![Figure 3.1 Railroads in the Study Region](image)

**Figure 3.1 Railroads in the Study Region**  
Source: 2003 Bureau Of Transportation Statistics Rail (1:100,000) scale Network Data
Figure 3.2 Airport Terminals in the Study Region

Source: Bureau of Transportation Statistics, Public Use Airports
CHAPTER 4

Database Development

This chapter deals with details of where the data was obtained and how the data was processed in order to meet the desired format.

4.1 Railroads Data

The Bureau of Transportation statistics website contains traffic and link characteristics data. The link database provides two shape files 1:100,000-scale network (“Rail100K”) and 1:200,000 scale network (“Rail2m”). The FRA website contains crossing inventory database. This database corresponds to node data.

4.1.1 Railroad Link by Link Database

The “Rail100k” shape file has data classified into different fields namely the railroad class, railroad owner and track age rights of the links/lines etc. The “Rail2m” shape file has the same attributes as “Rail100k” but it also contains the number of tracks, type of signal system operating on the link (i.e. absolute block system, centralized or manual traffic control system) and density on the links/lines as its additional fields.

4.1.2 Railroad Crossing Node Data

The railroad crossing data obtained from FRA website is a DBASE file. This file provide information about sidings, passing, train speeds, signals, number of tracks,
highway signals, at grades, percent trucks etc. Tables 4.1, 4.2 and 4.3 give an example of original format of data obtained for the above-specified three railroad databases.

Table 4.1 Example of Original Format of Rail (1:100,000 scale) Network Data

<table>
<thead>
<tr>
<th>ID</th>
<th>Length</th>
<th>FRAID</th>
<th>Railroad Owner</th>
<th>Track age Rights</th>
<th>State code</th>
<th>Railroad class</th>
<th>Railroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>110133</td>
<td>0.052991</td>
<td>110133</td>
<td>UP</td>
<td></td>
<td>AR</td>
<td>1</td>
<td>St Louis Southwestern Railway</td>
</tr>
<tr>
<td>110138</td>
<td>0.606049</td>
<td>110138</td>
<td>UP</td>
<td></td>
<td>BNSF</td>
<td>1</td>
<td>St Louis Southwestern Railway</td>
</tr>
<tr>
<td>110163</td>
<td>1.607407</td>
<td>110163</td>
<td>UP</td>
<td></td>
<td>AR</td>
<td>1</td>
<td>Missouri Pacific Railroad</td>
</tr>
<tr>
<td>110171</td>
<td>0.924548</td>
<td>110171</td>
<td>UP</td>
<td></td>
<td>BNSF</td>
<td>1</td>
<td>St Louis Southwestern Railway</td>
</tr>
<tr>
<td>115739</td>
<td>6.272729</td>
<td>115739</td>
<td>CSXT</td>
<td></td>
<td>GA</td>
<td>1</td>
<td>Family Lines</td>
</tr>
</tbody>
</table>

Source: Bureau of Transportation Statistics, Rail100K, 2003

Table 4.2 Example of Original Format of Rail (1:200,0000) scale Network Data

<table>
<thead>
<tr>
<th>ID</th>
<th>Length</th>
<th>Railroad Owner</th>
<th>Track age Rights</th>
<th>State code</th>
<th>Railroad class</th>
<th>Main track</th>
<th>Density</th>
<th>Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>7110</td>
<td>15.866315</td>
<td>CSXT</td>
<td>CPRS</td>
<td>MI</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>CTC</td>
</tr>
<tr>
<td>7174</td>
<td>20.243909</td>
<td>CN</td>
<td></td>
<td>MI</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>CTC</td>
</tr>
<tr>
<td>7190</td>
<td>10.028589</td>
<td>CN</td>
<td>AMTK</td>
<td>MI</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>CTC</td>
</tr>
<tr>
<td>7202</td>
<td>30.367990</td>
<td>CSXT</td>
<td></td>
<td>MI</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>CTC</td>
</tr>
<tr>
<td>7213</td>
<td>16.988495</td>
<td>SGVY</td>
<td></td>
<td>MI</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>MAN</td>
</tr>
</tbody>
</table>

Source: Bureau of Transportation Statistics, Rail2M, 2003

Table 4.3 Example of Original Format of Railroad Crossing Inventory Data

<table>
<thead>
<tr>
<th>Crossing ID</th>
<th>Railroad</th>
<th>Day thru</th>
<th>Day swt</th>
<th>Night thru</th>
<th>Night Swt</th>
<th>Max spd</th>
<th>Maxsppt</th>
<th>Min spd</th>
<th>Nosign</th>
<th>Othrtrks</th>
<th>Othrdes</th>
<th>State code</th>
</tr>
</thead>
<tbody>
<tr>
<td>004396U</td>
<td>BNSF</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>79</td>
<td>79</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>SIDING</td>
<td>IL</td>
</tr>
<tr>
<td>063689H</td>
<td>BNSF</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>0</td>
<td>40</td>
<td>40</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>SIDING</td>
<td>IL</td>
</tr>
<tr>
<td>063923W</td>
<td>BNSF</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td>IL</td>
</tr>
</tbody>
</table>

Source: Federal Railroad Administration, Crossing Inventory Database, 2003
4.1.3 Processing of Railroad Data

It was observed that the databases obtained from two different sources (BTS, FRA) have no common identification number for easy merging. Therefore the upper Midwest freight corridor study research team has developed an “Integrated Class I Railroad Network” (scale 1:100,000) shape file. This network is obtained by spatially joining the three databases i.e. the rail100k network, rail2m network and the crossing inventory database. Figure 4.1 shows the flow diagram for integrating the databases from two sources so that it could be used as an integrated class I railroad network. Table 4.4 shows common identification numbers for all the databases that were used for building an integrated network for capacity estimations.

Figure 4.1 Databases for Developing Integrated Class I Railroad Network
Table 4.4 Format and Common Identification Numbers in BTS, FRA and Integrated Railroad Network Databases

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DATA FILE</th>
<th>FORMAT</th>
<th>ATTRIBUTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTS</td>
<td>Rail2m</td>
<td>DBASE FILE</td>
<td>ID</td>
</tr>
<tr>
<td>BTS</td>
<td>Rail100K</td>
<td>DBASE FILE</td>
<td>ID</td>
</tr>
<tr>
<td>FRA</td>
<td>Crossing Link Table</td>
<td>DBASE FILE</td>
<td>ID</td>
</tr>
<tr>
<td>Output</td>
<td>Integrated Class I Railroad Network</td>
<td>SHAPE FILE</td>
<td>ID</td>
</tr>
</tbody>
</table>

Source: 2003 Bureau of Transportation Statistics Rail Data, FRA Crossing Inventory Data

4.1.4 Integrated Class I Railroad Network

The “Integrated Class I Railroad Network” is derived after integrating the data files obtained from BTS and FRA websites and creating a shape file having a unique identification number (“ID”). Furthermore, two common identification numbers, “FRAID100K” corresponding to “Rail100k” network table and “FRAID2M” corresponding to “Rail2m” network table were entered to output for easy identification.

The crossing link table has common identification numbers “ID” and “FRAID” in correspondence to integrated class I railroad network. Also it has “CROSSINGID1”, “CROSSINGID2”, “CROSSINGID3”, and “CROSSINGID4” corresponding to the crossing inventory database.
4.1.5 Process of Linking the Databases to Integrated Class I Railroad Network:

Initially the “rail2m” and “rail100K” link databases are joined to the network with help of common identification numbers namely “FRAID100K”, and “FRAID 2M”. Then, the crossing link table is joined with the crossing inventory database and linked back to the integrated network with help of “ID/FRAID”.

The database obtained after joining two databases has some repeated fields such as railroad owners, track age rights, abandoned lines, railroad class etc. These duplicate and redundant fields were removed so that data can be used for capacity analysis. The final base railroad network has 33,271 links. It becomes difficult to apply the rail capacity model on such a large database. Figure 4.2 shows the final base map network. Therefore, for the capacity analysis the railroad network should be selected based on segmentation.

4.1.6 Selected Railroad Network

The upper Midwest corridor railroad network contains around 33,271 railroad links. The Association of American Railroads (AAR), classified railroads in three categories on the basis of generation of revenues such as [20]:

**Class I** railroads are the major freight railroads operating about 71 percent of the total track miles in the U.S. They generate more than 91 percent of total rail freight revenues. According to Federal Surface Transportation Board, class I railroads generates revenue of more than $256.4 million each year.

**Class II** includes regional railroads with annual revenues between $40.5 million and $256.4 million. **Class III** includes local railroads with revenues less than $40.5 million.
Figure 4.2 Final Railroad Base Map Network

Source: 2004, Integrated Class I Railroad (1:100,000 scale) Network
The freight carried by the railroads is expressed in terms of density i.e., million gross ton mile/mile (MGTM/MI). The density of the line ranges from 0-7, where 0 means it is an abandoned line and 7 means that the line can carry freight more than 100 million gross tons. Generally class I railroads have density of 1 to 7. In the upper Midwest freight corridor study region the following major railroad owners own the class I railroads:

1. Burlington Northern Santa Fe (BNSF)
2. CSX Transportation (CSXT)
3. Canadian Pacific Rail lines (CPRS)
4. Canadian National Rail lines (CN)
5. Norfolk and Southern Railroads (NS)
6. Union Pacific Railroad (UP)
7. Wisconsin central Railroad (WC).

The class I railroads connect all intermodal terminals and major cities in the study region. Forty two percent of the total track miles in the study region are classified as class I. Each link carries a maximum of 100 million gross tonnages of goods. Because of the bulk of freight carried by class I railroads, only class I railroads are initially considered as of prime importance. Figure 4.2 shows the class I railroads by owner in the study region. A method is developed to select the class I railroad segments from the class I railroads for capacity analysis. The segment of class I railroad consists of

- Railroad connecting two major cities
- Railroad intersecting other class I railroad
- Railroad connecting the intermodal terminals
Railroad consisting of similar operating conditions (Single track, Double track)

Figure 4.3 shows the conceptual development of class I railroad segments. The process of segmentation is shown in the Figure 4.4. Figure 4.5 shows the selected railroad network for capacity analysis. As seen, network contains segments connecting the intermodal terminals and major cities.

Figure 4.3 Conceptual Development of Class I Railroads
Midwest Freight Corridor
Integrated Class I railroad network (1:100,000 scale).

Railroad by owner shape files
(i.e. BNSF.shp, AMTK.shp, CN.shp etc.)

Segment Definition:
A Segment line consists of
Railroad connects two major cities.
Railroad intersecting other class I rail line.
Railroad connects the Intermodal terminals.
*Railroad having similar operating conditions (Single track, Double track).

SEG_NO (Segment NO)

Segments by Railroad Owners

Railroad Network thematic map showing Segments. (As shown in Figure 4.5)

Figure 4.4 The Process of Segmentation
Figure 4.5 Selected Railroad Network for Capacity Analysis

Source: 2004, Integrated Class I Railroad (1:100,000 scale) Network
The selection criterion based on segments was performed on “Integrated class I railroad network” to obtain a selected railroad network for capacity analysis as seen in Figure 4.5. For capacity estimations out of all the attributes in the selected railroad network only main variables were used. A new database called rail segment network with the main variables is extracted from the base selected railroad network using the “DISSOLVE” tool based on common identification number “SEG_NO” and capacity estimations are done for each segment. After calculations are performed rail segment network is linked back to the base selected railroad network with the help of the same common identification number “SEG_NO”.

Table 4.5 shows some of the main variables useful for capacity calculations obtained from crossing inventory data. Figure 4.6 shows the flow diagram how the databases are arranged to obtain the final rail network that can be used directly for applying the railroad capacity model.

**Table 4.5 Main Variables used for Capacity Estimations**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signals</td>
<td>The information about number of signals on the link is obtained from NOSIGN</td>
</tr>
<tr>
<td></td>
<td>(indicates whether there is signal present or not), SIGNLEQP (Indicates whether signal is equipped to the track or not).</td>
</tr>
<tr>
<td>Sidings</td>
<td>The information of sidings is obtained from number of OTHTRTRKS. (Even check the description)</td>
</tr>
<tr>
<td>Speed</td>
<td>The information of speed is obtained from Maximum timetable speed, Maximum speed)</td>
</tr>
<tr>
<td>Train frequencies</td>
<td>The number of trains moving on link is obtained from TOTRNS (Total trains).</td>
</tr>
</tbody>
</table>
Figure 4.6 Flow of Activities to Generate Final Database for Class I Railroad Network
4.2 Airport Terminals Data

The airport terminal data is available on the Bureau of Transportation Statistics website, in Air Carrier Statistics (Form 41 Traffic). The three different types of data files are available:

1. T-100-segment database
2. Public use runways
3. Public use airports

The T-100 segment database combines domestic and international segment data by U.S. and foreign air carriers. It contains data on aircraft type, service class for passengers transported, freight and mail transported available capacity. This segment database contains monthly data obtained from January to December. Therefore in this study, there was a need to select particular months data for the study. It is observed that Chicago O’ Hare International airport (ORD) is one of the major airports in the study region having maximum arrivals and departures. Figures 4.7 and 4.8 depict the maximum arrivals and departures at the ORD airport for each month respectively. As seen in the plots maximum arrivals (96 aircrafts/hour) and maximum departures (96 aircrafts/hour) were observed in the month of August and December. So either of the data could be used for the study but the August data was considered for the research because August data showed maximum arrivals and departures for almost all major airports in the study region whereas, December showed maximum arrivals and departures for only Chicago O’ Hare International airport (ORD) as seen in Figures 4.9 and 4.10.
Figure 4.7 Monthly Arrivals (aircrafts/hour) for Chicago O’Hare International Airport (ORD)

Source: Bureau of Transportation Statistics, T-100 Segment Database, 2003

Figure 4.8 Monthly Departures (aircrafts/hour) for Chicago O’Hare International Airport (ORD)

Source: Bureau of Transportation Statistics, T-100 Segment Database, 2003
Figure 4.9 Maximum Frequencies of Arrivals
Source: Bureau of Transportation Statistics, T-100 Segment Database, 2003

Figure 4.10 Maximum Frequencies of Departures
Source: Bureau of Transportation Statistics, T-100 Segment Database, 2003

The Public Use Airport Runways database is a geographic point dataset of runways in the United States and US territories containing information on the physical characteristics of the runways. This geospatial data is derived from the FAA's National Airspace System Resource Aeronautical Data Product (Effective 23 January 2003). This
data provides users with information about the runway locations and attributes for national and regional analysis applications.

The Public-Use Airports database is a geographic point database of aircraft landing facilities in the United States and U.S. Territories. Attribute data is provided on the physical and operational characteristics of the landing facility, current usage including enplanements, aircraft operations and congestion levels. BTS provides data on usage categories also.

4.2.1 Processing the Airport Terminals Data

The T-100 segment data for month of August is SUMMARIZED based on origin and destination airports in the study region using ARC GIS. The Public use runways shape file is SUMMARIZED based on LOCID to find the number of runways in each airport. Then the two databases, the summarized Public use runways database and summarized T-100 segment database, are joined to the Public use Airports database based on common identification number “LOCID”. This final database gives the information about the number of runways, arrivals, departures, incoming and outgoing freight at each airport. Figure 4.11 shows the flow diagram explaining how the databases are joined and Table 4.6 shows the format of the final airport terminal database.
Figure 4.11 Flow diagram Showing the Joining of Airports Database
Table 4.6 Example of Format of Final Airport Terminals Database

<table>
<thead>
<tr>
<th>LOC ID</th>
<th>Airport name</th>
<th>State code</th>
<th>Number of Runways</th>
<th>Daily arrivals</th>
<th>Daily departures</th>
<th>Incoming freight (pounds)</th>
<th>Outgoing freight (Pounds)</th>
<th>Payload (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRL</td>
<td>SOUTHEAST IOWA REGIONAL</td>
<td>IA</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>296400</td>
</tr>
<tr>
<td>CIN</td>
<td>ARTHUR N NEU</td>
<td>IA</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2100</td>
</tr>
<tr>
<td>CID</td>
<td>THE EASTERN IOWA</td>
<td>IA</td>
<td>2</td>
<td>45</td>
<td>44</td>
<td>2884408</td>
<td>2972744</td>
<td>21854374</td>
</tr>
<tr>
<td>DSM</td>
<td>DES MOINES INTL</td>
<td>IA</td>
<td>2</td>
<td>70</td>
<td>69</td>
<td>8892381</td>
<td>8375652</td>
<td>49953964</td>
</tr>
</tbody>
</table>

Source: Bureau of Transportation Statistics, Public Use Airports, Public Use Runways, T-100 Segment Data

It is time consuming to estimate capacity of each and every airport terminal in the study region. Thus a selection criterion is needed to attain major airports in the study region.

4.2.2 Selection Criteria for Airports

There are around 103 airports in the upper Midwest freight corridor study region. Most of the airports have no daily flight arrival/departures and therefore an elimination process is adopted for selection of airports. The criterion used in the elimination process is as follows:

- To eliminate all airports having zero hourly arrivals and departures
- To eliminate all airports those are not lying within 5-mile distance from the intermodal facilities
- To eliminate all airports with monthly freight volume less than 20 tons
As a result of the elimination, nineteen airports were obtained and these were considered for the study. Figure 4.12 shows the selected airports in the study region. Table 4.7 shows the list of selected airport terminals showing the airport terminal site number, airport location ID, state, city and name of airport terminal. Table 4.8 shows the hourly arrivals, departures in terms of aircrafts/hour and monthly incoming, outgoing freight tons per month of the selected airports.
Figure 4.12 Selected Airport Terminals in the Upper Midwest Freight Corridor Study Region

Source: Bureau of Transportation Statistics, Public Use Airports Data
<table>
<thead>
<tr>
<th>S.N0</th>
<th>SITE_NO</th>
<th>LOC_ID</th>
<th>STATE</th>
<th>CITY</th>
<th>AIRPORT NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>05884. *A</td>
<td>CID</td>
<td>IA</td>
<td>Cedar Rapids</td>
<td>The Eastern Iowa</td>
</tr>
<tr>
<td>2</td>
<td>05950. *A</td>
<td>DSM</td>
<td>IA</td>
<td>Des Moines</td>
<td>Des Moines Intl</td>
</tr>
<tr>
<td>3</td>
<td>04507. *A</td>
<td>MDW</td>
<td>IL</td>
<td>Chicago</td>
<td>Chicago Midway Intl</td>
</tr>
<tr>
<td>4</td>
<td>04508. *A</td>
<td>ORD</td>
<td>IL</td>
<td>Chicago</td>
<td>Chicago O’Hare Intl</td>
</tr>
<tr>
<td>5</td>
<td>04868. *A</td>
<td>MLI</td>
<td>IL</td>
<td>Moline</td>
<td>Quad City Intl</td>
</tr>
<tr>
<td>6</td>
<td>04938. *A</td>
<td>PIA</td>
<td>IL</td>
<td>Peoria</td>
<td>Greater Peoria Regional</td>
</tr>
<tr>
<td>7</td>
<td>04974. *A</td>
<td>RFD</td>
<td>IL</td>
<td>Rockford</td>
<td>Greater Rockford</td>
</tr>
<tr>
<td>8</td>
<td>05282. *A</td>
<td>FWA</td>
<td>IN</td>
<td>Fort Wayne</td>
<td>Fort Wayne International</td>
</tr>
<tr>
<td>9</td>
<td>05375. *A</td>
<td>IND</td>
<td>IN</td>
<td>Indianapolis</td>
<td>Indianapolis Intl</td>
</tr>
<tr>
<td>10</td>
<td>05661. *A</td>
<td>SBN</td>
<td>IN</td>
<td>South Bend</td>
<td>South Bend Regional</td>
</tr>
<tr>
<td>11</td>
<td>09749. *A</td>
<td>DTW</td>
<td>MI</td>
<td>Detroit</td>
<td>Detroit Metropolitan Wayne County</td>
</tr>
<tr>
<td>12</td>
<td>09809. *A</td>
<td>FNT</td>
<td>MI</td>
<td>Flint</td>
<td>Bishop International</td>
</tr>
<tr>
<td>13</td>
<td>09852. *A</td>
<td>GRR</td>
<td>MI</td>
<td>Grand Rapids</td>
<td>Gerald R. Ford International</td>
</tr>
<tr>
<td>14</td>
<td>09986. *A</td>
<td>AZO</td>
<td>MI</td>
<td>Kalamazoo</td>
<td>Kalamazoo/Battle Creek International</td>
</tr>
<tr>
<td>15</td>
<td>10824. *A</td>
<td>MSP</td>
<td>MN</td>
<td>Minneapolis</td>
<td>Minneapolis-St Paul Intl/Wold-Chamberlain</td>
</tr>
<tr>
<td>16</td>
<td>17746. *A</td>
<td>CLE</td>
<td>OH</td>
<td>Cleveland</td>
<td>Cleveland-Hopkins Intl</td>
</tr>
<tr>
<td>17</td>
<td>18577. *A</td>
<td>TOL</td>
<td>OH</td>
<td>Toledo</td>
<td>Toledo Express</td>
</tr>
<tr>
<td>18</td>
<td>27013.1*A</td>
<td>ATW</td>
<td>WI</td>
<td>Appleton</td>
<td>Outagamie County Regional</td>
</tr>
<tr>
<td>19</td>
<td>27388. *A</td>
<td>MKE</td>
<td>WI</td>
<td>Milwaukee</td>
<td>General Mitchell International</td>
</tr>
</tbody>
</table>

Source: Bureau of Transportation Statistics Public Use Airports Data
### Table 4.8 Hourly Arrivals and Departures and Freight Volumes of Selected Airports

<table>
<thead>
<tr>
<th>SITE NO</th>
<th>LOC_ID</th>
<th>Number of Hourly Departures</th>
<th>Number of Hourly Arrivals</th>
<th>Incoming freight (Tons/month)</th>
<th>Outgoing freight (Tons/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05884. *A</td>
<td>CID</td>
<td>4</td>
<td>3</td>
<td>1442</td>
<td>1486</td>
</tr>
<tr>
<td>05950. *A</td>
<td>DSM</td>
<td>5</td>
<td>5</td>
<td>4446</td>
<td>4188</td>
</tr>
<tr>
<td>04507. *A</td>
<td>MDW</td>
<td>24</td>
<td>24</td>
<td>1475</td>
<td>1360</td>
</tr>
<tr>
<td>04508. *A</td>
<td>ORD</td>
<td>96</td>
<td>94</td>
<td>79053</td>
<td>63159</td>
</tr>
<tr>
<td>04868. *A</td>
<td>MLI</td>
<td>2</td>
<td>2</td>
<td>77</td>
<td>57</td>
</tr>
<tr>
<td>04938. *A</td>
<td>PIA</td>
<td>2</td>
<td>2</td>
<td>2285</td>
<td>2652</td>
</tr>
<tr>
<td>04974. *A</td>
<td>RFD</td>
<td>1</td>
<td>1</td>
<td>7556</td>
<td>8358</td>
</tr>
<tr>
<td>05282. *A</td>
<td>FWA</td>
<td>4</td>
<td>3</td>
<td>6243</td>
<td>6734</td>
</tr>
<tr>
<td>05375. *A</td>
<td>IND</td>
<td>16</td>
<td>17</td>
<td>40028</td>
<td>42178</td>
</tr>
<tr>
<td>05661. *A</td>
<td>SBN</td>
<td>3</td>
<td>3</td>
<td>871</td>
<td>855</td>
</tr>
<tr>
<td>09749. *A</td>
<td>DTW</td>
<td>50</td>
<td>51</td>
<td>10240</td>
<td>8536</td>
</tr>
<tr>
<td>09809. *A</td>
<td>FNT</td>
<td>3</td>
<td>3</td>
<td>773</td>
<td>582</td>
</tr>
<tr>
<td>09852. *A</td>
<td>GRR</td>
<td>5</td>
<td>5</td>
<td>1619</td>
<td>1471</td>
</tr>
<tr>
<td>09986. *A</td>
<td>AZO</td>
<td>2</td>
<td>2</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>10824. *A</td>
<td>MSP</td>
<td>52</td>
<td>52</td>
<td>14016</td>
<td>14269</td>
</tr>
<tr>
<td>17746. *A</td>
<td>CLE</td>
<td>24</td>
<td>24</td>
<td>4106</td>
<td>4041</td>
</tr>
<tr>
<td>18577. *A</td>
<td>TOL</td>
<td>3</td>
<td>3</td>
<td>8036</td>
<td>8658</td>
</tr>
<tr>
<td>27013.1*</td>
<td>ATW</td>
<td>2</td>
<td>2</td>
<td>494</td>
<td>431</td>
</tr>
<tr>
<td>27388. *A</td>
<td>MKE</td>
<td>17</td>
<td>17</td>
<td>4436</td>
<td>4455</td>
</tr>
</tbody>
</table>

Source: Bureau of Transportation statistics, Air carrier statistics data.

The capacity estimations are performed on the selected railroad network and selected airports.
Chapter 5

Methodology

This section deals with capacity algorithms developed to estimate capacity for selected railroad segments and airport terminals in the study region. It also deals with computer program developed for railroad capacity estimation. Considering the different methods discussed in literature review the regression method developed by Peat, Marwick, Mitchell and Co. was chosen for the railroad capacity study. This method has been well documented and widely used in various disciplines. For airport terminals study, both the methodologies specified in literature review were chosen.

5.1 Railroad Capacity Algorithm

An algorithm developed by PMM&Co (Peat, Marwick, Mitchell and Co 1975) [21] for FRA is used to estimate railroad capacity. The algorithm defines capacity as a function of delay. The main parameters causing delay are classified into three categories: Plant, Traffic and Operating parameters. Furthermore, plant parameters are length, sidings and crossover spacing, traffic parameters are speed limit and operating parameters are track outages, train stop time and maximum trip time. Using regression techniques, PMM&Co developed a set of equations for a 100-mile line to estimate the combined effect of these parameters on the railroad capacity. This model can be used for railroads upto four tracks.
The railroad capacity model algorithm is given by the following equations:

The Railroad Capacity is given by equation 5.1

\[ C = \frac{Ac}{K} \times \left( \frac{100}{L} \right). \]  \[---- 5.1\]

Where,

\[ C = \text{Capacity of the railroad trains per day} \]
\[ Ac = \text{Average delay per train at capacity (in hours)} \]
\[ K = \text{Delay slope} \]
\[ L = \text{Length of line in Miles} \]

The Average delay per train depends on the number of tracks and operating characteristics.

Thus, for Single Track, it is given by equation 5.2

\[ Ac = \left[ - b + \sqrt{b^2 - 4 \times a \times c} \right] / 2a \]  \[----5.2\]

Where,

\[ a = 973.125 \times \frac{S}{L} \times L \]
\[ b = \frac{(67.2765 \times P + 151.7085 \times D)}{L} \]
\[ c = 1.41432 - M \times (150/L) + 150/S + I \]

For Double Track, it is given by equation 5.3

\[ Ac = 0.031274 \times L \times \frac{84636.1}{150/150} \times \frac{1}{1 - 1.84636} \]  \[----5.3\]

Where,

\[ M = \text{Maximum allowable total trip time} \]
\[ S = \text{Speed of the slowest class of through freight trains} \]
\[ P = \text{Dispatch peaking factor} \]
P = (Trains per peak hour during peak/trains per peak during off peak) -1

D = Directionality factor

(Trains in Dominant direction / trains in opposite direction) –1

I = Amount of imposed delay on regular freight Trains. (Includes Start and Stop time)

P, D, I default values assumed the models are

P = 0
D = 0
I = 1.233

To estimate the effects on delay slopes with change in parameter values, a fractional approach was adopted. The delay slopes for modified (changed) cases were developed as fractions of the base case delay slope. It is given by equation 5.4

\[ F_{oi} = \left( \frac{K_i}{K} \right)^{Pi} \] ----5.4

Where,

F_{oi} = Delay slope adjustment factor (obtained from simulations)

K_i = Delay slope for the change in parameter i

K = Delay slope for the base case

Pi = Percent change in parameter i

\[ Pi = \frac{(Vi - Vo)}{[0.5*(Vi + Vo)]} \]

Vo = Value of the Parameter in the base case

Vi = Changed value of the parameter

In multiple modification cases slope increasing modifications and slope decreasing modifications are multiplied.
An estimate of \( F_{om} \) from the individual component modifications is given by equation 5.5

\[
F_{om} = C_I * C_D^{-1}
\] ----5.5

Where,
\[
C_I = \text{component of factors that increase the slope}
\]
\[
C_D = \text{component of factors that decrease the slope}
\]

Therefore the multiple modification delay slope is given by equation 5.6.

\[
K_i = K * C_I * C_D
\] ----5.6

The Figure 5.1 shows the flow diagram explaining the railroad capacity algorithm.

### 5.1.1 Railroad Capacity Program

For estimation of railroad capacity, a computer program is written in Microsoft Visual Basic. This program uses the PMM&Co [15] algorithm developed for FRA. The algorithm was primarily developed as a commuter train dispatching simulation model. The program calculates the practical railroad capacity and the track utilization factor. The track utilization factor calculated here is the ratio of usage to practical capacity (TUF). The TUF is helpful in identifying the bottlenecks and areas with excess capacity.

Appendix A provides the detail coding of capacity program and Figure 5.2 shows the flow diagram explains the three steps followed to apply the program to the selected railroad network to obtain the railroad capacity. The capacity is shown in terms of number of trains per day. By using present track utilization data the track utilization factors (TUF) are estimated.
INPUT MODIFIED DATA
Vi = Plant Parameters, Traffic Parameters, Operating parameters

foi = Delay Slope adjustment factor (Simulation Results).table5.3(2)

Compare with Base value Parameters (Vo) Table 5.4 (PMM&CO, 1975)

Calculate Proportional Factor
Pl = (Vi - Vo/0.5*(Vi + Vo)

Ci = Slope increasing components
(∑ (foi) ^ Pi) – (Ni - 1)
foi ≥ 1
Ni = Number of slope increasing

Cd = Slope decreasing components
(∑ (foi) ^ Pi) – (Nd - 1)
foi < 1
Nd = Number of slope decreasing modifications.

fom = Ci / Cd

Ki = Delay slope for Multiple modification case.
Km = fom*Ko
K = Delay Slope from table 5.3 (PMM&CO, 1975)

Ac = Average delay per train (in hours).

CAPACITY = (Ac/k) * (100/L)

Figure 5.1 Flow of Activities in Railroad Capacity Algorithm
3. Results:
Railroad Capacity
Number Of Trains per day
Track Utilization Factor

2. Model USING Visual Basic in Excel

1. Rail Segment Network

Program results displayed in the EXCEL sheet are exported to DBASE file for display of a thematic map showing Track Utilization Factor (TUF) of selected railroad segment in Arc Map/Arc view.

5.2 Airport Terminals Ultimate Capacity

In this research two methodologies are used to calculate the ultimate capacity. These are Federal Aviation Administration (FAA 1976)(6) graph based methodology by International Association of Traffic and Safety Sciences (IATSS) Journal [14] based mathematical methodology.

Runway capacity estimations procedure obtained from the latter is given below.

The runway capacity is given by equation 5.7 as

\[
C = \frac{7200}{(t_a + t_d)} \quad ---5.7
\]

Where,
C = runway capacity in terms of number of aircrafts/hour.

t_a = runway occupancy time of arriving aircraft (65 seconds assumed).

t_d = runway occupancy time of departing aircraft (60 seconds assumed).

The IATSS assumes 60 seconds for heavy aircrafts and 50 seconds for other aircrafts.

The graphical approach to determine runway capacity is obtained from Department of Transportation, FAA, and Systems Research and Development Services (FAA 1976). The main parameters required for graphical approach are the aircraft mix, percent arrivals, percent touch and go (A landing immediately followed by a takeoff), and exit taxiways. The aircraft mix is expressed in terms of mix index. Table 5.1 shows the aircraft classification given by Federal Aviation Administration.

For calculation purpose the parameters are given as

Mix Index = Percent of Aircraft in Class C + 3 * Percent of Aircraft in Class D.

- Percent arrivals = \( \frac{(A+1/2(T+G))}{(A+D+(T+G))} \)*100

- Percent Touch and go = \( \frac{(T+G)}{(A+(T+G))} \)*100

Where,

A = Number of arrival operations in an hour.

D = Number of departure operations in an hour.

T+G = Number of touch and go operations in an hour.
Table 5.1 Aircraft classification by type.

<table>
<thead>
<tr>
<th>Aircraft classification</th>
<th>Type of Aircraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class A</td>
<td>Small single engine aircraft weighing 12,500 lb or less.</td>
</tr>
<tr>
<td>Class B</td>
<td>Small twin-engine aircraft weighing 12,500 lb or less and Lear jets.</td>
</tr>
<tr>
<td>Class C</td>
<td>Large aircrafts weighing more than 12,500 lb up to 300,000 lb.</td>
</tr>
<tr>
<td>Class D</td>
<td>Heavy Aircraft weighing more than 300,000 lb.</td>
</tr>
</tbody>
</table>

Source: Aircraft Classification given by Federal Aviation Administration.

Note: weights refer to maximum certificated takeoff weight.

The following assumptions are made for the use of monographical method

1. It is assumed that there are four exit taxiway locations, therefore exit factor = 1.00

2. It is assumed that there are zero percent touch and go flights, therefore touch go factor = 1.00

The estimated parameters are used in the monographical stepwise process as:

- Step 1. Determine the mix index, percent arrivals, percent touch and go and location of exit taxiways from the final selected database.
- Step 2. From the graph (shown in Figure 2.10) match the percent arrivals and mix index and determine the hourly base capacity ‘C’.
- Step 3. Multiply hourly base capacity with the touch and go factor and exit factor to obtain the ultimate single runway capacity.
The maximum ultimate capacity of airport is calculated by multiplying the obtained runway capacity with number of runways in the airport. The study also shows the percent-unused capacity. This is estimated by comparing calculated maximum ultimate capacity to the total operations i.e., sum of number of hourly arrivals and departures at the airport. Figure 5.3 shows the flow diagram explaining the methodologies followed in this study to estimate the airport capacity.

![Figure 5.3 Flow Chart Showing the Methodologies Used for Airport Capacity Study](image-url)
5.2.1 Maximum Number of Passenger and Freight Flights within the Intercity Corridor

To find maximum number of passenger/ freight aircrafts served by each intercity corridor, the ultimate capacity at each airport is found and is multiplied with the maximum person /freight occupancy per aircraft.

The maximum number of passenger and freight aircraft served by intercity corridor is given in equations 5.8 and 5.9 as

\[
C_{\text{passenger}} = C_A \ast P_A \ast D_{AB} + C_B \ast P_B \ast D_{BA} \quad ----5.8
\]

Where,

\[
C_A = \text{Ultimate capacity at Airport A.}
\]

\[
P_A = \text{Percent passenger flights in Airport A}
\]

\[
D_{AB} = \text{Percent daily flights from Airport A to Airport B}
\]

\[
C_B = \text{Ultimate capacity at Airport B}
\]

\[
P_B = \text{Percent passenger flights in Airport B}
\]

\[
D_{BA} = \text{Percent daily flights from Airport B to Airport A.}
\]

\[
C_{\text{freight}} = C_A \ast F_A \ast D_{AB} + C_B \ast F_B \ast D_{BA} \quad ----5.9
\]

Where,
\( C_A = \) Ultimate capacity at Airport A

\( F_A = \) Percent freight flights in Airport A

\( D_{AB} = \) Percent daily flights from Airport A to Airport B

\( C_B = \) Ultimate capacity at Airport B

\( F_B = \) Percent freight flights in Airport B

\( D_{BA} = \) Percent daily flights from Airport B to Airport A
Chapter 6

Results and Discussions

This chapter summarizes the applications of the implemented procedures discussed previously for estimating the capacity of railroads and airport terminals in the study region.

6.1 Railroads

The railroad capacity program derives inputs from the integrated class I railroad network file and estimates the capacities by segment. The output from the program is displayed in database file. This database file is used to display a thematic map in Arc Map/ Arc View. The capacity program helps in identifying the segments of the railroad network having limited capacity (i.e. potential bottlenecks) or excess capacity using the track utilization factor (TUF). The Track Utilization Factor (TUF) is defined as the ratio of usage capacity to practical capacity. TUF < 0.50 provides an indication of the additional traffic volume (available capacity) that could be handled by the system while not exceeding the defined threshold. A TUF > 1.00 indicates the potential bottlenecks in the network.

Figure 6.1 shows the color-coded capacity of railroad network in the study region in terms of TUF. Table 6.1 shows the sample results obtained by running the model.
Figure 6.1 Track Utilization Factor for Railroad Segments
<table>
<thead>
<tr>
<th>Seg_No</th>
<th>Seg_Length</th>
<th>Railroad Owner</th>
<th>Main Track</th>
<th>Average Speed (mph)</th>
<th>Average Signal Spacing (miles)</th>
<th>Average Side Space (miles)</th>
<th>Maximum trip time (hours)</th>
<th>Average train delay (hours)</th>
<th>Maximum Practical Capacity (Trains /day)</th>
<th>Observed Maximum Trains (Trains /day)</th>
<th>Track Utilization Factor</th>
<th>Track Condition</th>
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<td>18</td>
<td>0.72</td>
<td></td>
</tr>
</tbody>
</table>
6.1.1 List of Some Significant Bottlenecks in the Study Region

1. The railroad segment owned by CSX Transportation is located near the Vickers/Wales road at grade crossing and intersects the Norfolk Southern railroad. The TUF of this segment might be improved by increasing the track speed.

2. The railroad segment owned by CSX Transportation from Indianapolis to Cincinnati passing by Indiana polis bulk transfer (INRD) terminal. This segment might be improved by expanding the existing single track to double track.

3. The Burlington Northern Santa Fe located near Chicago intersected by Canadian National railroad and passing by GATX cargo terminal, Bulkmatic terminal-summit, CSXI Bedford Park is one of the potential bottlenecks identified in the study. The main reason for this segment in having TUF >1.00 is because of the low operating speed (i.e. around 14mph).

4. The Burlington Northern Santa Fe passing near St.Paul intersected by Union Pacific. This single track might be expanded to double track.

5. The Canadian Pacific Railroad near Milwaukee and passing by the intermodal terminal Mindemann trucking – Ixonia. This railroad segment might be expanded to double track.

6. The Norfolk Southern near Lansing heading towards Ann Arbor. This segment has more signal spacing. This segment might be improved by decreasing the signal spacing.

6.1.2 Limitations of the Railroad Capacity Study:

The study has seven segments whose maximum practical capacity approached and or exceeded theoretical capacity. The reasons identified for such conditions are:
• Segments having number of tracks greater than two
• Segments having very high operating speed (i.e. around 60-80mph)

Table 6.2 shows railroad segments in the study region approaching and or exceeding the theoretical capacities.

### Table 6.2 Railroad Segments Approaching Theoretical Capacity

<table>
<thead>
<tr>
<th>Seg_No</th>
<th>Railroad Owner</th>
<th>Main track</th>
<th>Signals</th>
<th>Seg Length (miles)</th>
<th>Observed Maximum Number of Trains</th>
<th>Average speed (mph)</th>
<th>Average Signal spacing (miles)</th>
<th>Average side space (miles)</th>
<th>Maximum Trip time (hours)</th>
<th>Capacity (Trains /day)</th>
<th>TUF</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>BNSF</td>
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</table>

### 6.1.3 Effect of Parameters on Capacity:

Figure 6.2 is the plot between the Average speed and delay slope. The plot shows decreasing delay slope with increasing average speed thus indicating an increase in the capacity. Double tracks were identified to have lesser delay compared to single track.

The results of Railroad capacity model (Table 6.1) show that parameters such as signal spacing, siding spacing, and length and trip time have effect on capacity along with speed. Appropriate signal spacing (1-3 miles) and siding spacing (5–21.4 miles) also help in increasing the capacity.
Figure 6.2 Graph Showing Relationships Between Delay Slope and Average Speed

6.2 Airports

The study on airports is divided into two steps; initially using the methods suggested by the FAA and the IATSS the airside capacity of the selected airports is estimated. After capacity estimation the ultimate airport capacity is used for determining the number of passenger, freight aircraft served within intercity major airports corridor. Table 6.3 shows the airside capacity for airports in the study region, Table 6.4 shows the number of passenger aircrafts per hour served within intercity corridors, Table 6.5 shows the number of freight aircrafts per hour served within intercity corridors and Table
6.6 shows the freight volume (tons/month). As discussed earlier, the airside capacity governs the capacity of airport.

The FAA and the IATSS analysis revealed the following:

- From the percent-unused capacity column in Table 6.3 it can be concluded that most of major airports in study region have 50 percent or higher unused capacity.
- The Chicago’ O Hare International Airport (ORD) has maximum arrivals and departures with ultimate capacity of 336 –406 aircraft/hour (Table 6.3).
- The maximum number of passenger flights (98 aircrafts/hour) is served by ORD –DTW corridor (Chicago and Detroit). Table 6.4 shows the number of passenger aircrafts per hour served within the intercity corridor.
- The maximum number of freight flights (8 aircrafts/hour) is served by DSM-RFD corridor (Des Moines and Rockford) and ORD- PIA corridor (Chicago and Peoria). Table 6.5 shows the number of freight aircrafts per hour served within the intercity corridor.
- The ORD-IND (Chicago – Indianapolis) corridor carries maximum monthly freight (Property, other than express and passenger baggage transported by air) of 2441 tons per month. Table 6.6 shows the freight tonnage carried within the intercity corridor in the study region.

The thematic map for selected railroads and airports can be found on the upper Midwest freight corridor study website which is hosted by GISAG center of the University of Toledo. It is easy to use thematic map to obtain information for a particular
segment of railroad network or particular airport of interest by pointing and clicking on the segment or airport terminal.

The above results show that the methodology followed in this research can be applied for wide range study regions. Planners, shippers and policy makers can make use of the above findings and results for future statewide planning and implementation of necessary measures for the improvement of bottlenecks.
Table 6.3 Airside Capacities for Selected Airports

<table>
<thead>
<tr>
<th>LOCID</th>
<th>Hourly Arrivals</th>
<th>Hourly Departures</th>
<th>Number of Runways</th>
<th>Maximum Runway Capacity (Graph)</th>
<th>Ultimate Runway Capacity (IATSS)</th>
<th>Total Operations</th>
<th>Unused Capacity (Graph)</th>
<th>Unused Capacity (IATSS)</th>
<th>Percent Unused Capacity (Graphical)</th>
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Source: Bureau of Transportation statistics, Public use Runways, Air Carrier Statistics

Note: The Total operations, arrivals, departures, capacity are all expressed in terms of aircrafts per hour.
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Source: Bureau of Transportation Statistics, Air Carrier Statistics
Chapter 7

Summary and Conclusions

Results from the research summarize that the parametric tool developed by Peat, Marwick, Mitchell &Co is an effective decision support tool for capacity estimations. It also demonstrates the feasibility of using the two methodologies suggested by IATSS and FAA recommended graphical method for airport capacity estimations.

The following conclusions can be drawn from the study:

1. The most important parameter in determining capacity, other than the number of tracks, is the operating speed.
2. Some of the single and double track segments approach the theoretical capacities when the operating speeds are moderately high.
3. Double track experiences less delay compared to single track.
4. It is observed that railroad capacity is function of delay; the delay in turn is a function of plant, traffic and operating parameters.
5. It is observed that most of the segments block length ranges from 0.8 to 3 miles and the siding spacing ranges from 4- 25 miles.
6. It is observed that 18% of the selected segments in the study region are potential bottlenecks, which need to be improved.
7. The airside capacity is considered as an important measure to represent the airport capacity. The runway is the most important factor to be considered for the airside capacity estimation.

8. It was observed that most of the airports have 50% or higher unused capacity.

9. It was also observed that graphical method gave more conservative results compared to the mathematical method.
Recommendations

- In this research number of tracks, speed, sidings spacing and signal spacing were considered as the important parameters for estimating the capacity in the study region. There are other variables such as track outages, train stop time and train priorities that can be explored for improvement of the railroad capacity. Extending the analysis for more number of tracks could also be looked up.

- Similarly, for airside capacity only runway was considered as an important parameter for capacity. There are other variables such as taxiways, gates that can also be considered for more accurate capacity estimations could be made.

- In this research rail (1:100,000 scale) network, rail (1:2,000,000 scale) network and crossing inventory database were joined together to form integrated rail (1:100,000 scale) network. Due to problem associated with spatial join there were some errors in data such as one link taking the attributes of other nearby link leaving the actual link. To avoid these errors it is strongly recommended to maintain databases having same common identifications and same geo referencing.

- Another significant step would be to maintain complete database without gaps for all the states. This would enable the researchers to estimate the accurate capacities.
REFERENCES


Visual Basic code for estimating Railroad capacity.

Private Sub display_results_Click()

Dim totalrows As Integer, Number_signals(300) As Integer, Number_sidetracks(300) As Integer, seg_id As Integer, number_tracks(300) As Integer
Dim Totaltrains_observed(300) As Integer, Number_sign(300) As Integer, Number_sidings(300) As Integer, Number_crossings(300) As Integer
Dim Number_othtrtrks(300) As Integer, Number_sidetk(300) As Integer, Number_signl(300) As Integer
Dim Nispeed(300) As Integer, Niblocklength(300) As Integer, Nisidespace(300) As Integer
Dim Ndspeed(300) As Integer, Ndblocklength(300) As Integer, Ndsidespace(300) As Integer, introw As Integer
Dim Capacity(300) As Integer
Dim xlapp As Object
Dim XLBOOK As Object
Dim length(300) As Single, average_blocklength(300) As Single, average_sidespace(300) As Single, A1 As Single, B1 As Single, C1 As Single, maximum_triptime(300) As Single, Average_speed(300) As Single
Dim Base_speed As Single, Base_blocklength As Single, Base_sidespace As Single
Dim Pispeed(300) As Single, Piblocklength(300) As Single, Pisidespace(300) As Single
Dim Foispeed(300) As Single, Foiblocklength(300) As Single, Foisidespace(300) As Single
Dim Cispeed(300) As Single, Ciblocklength(300) As Single, Cisidespace(300) As Single
Dim Cdspeed(300) As Single, Cdblocklength(300) As Single, Cdsidespace(300) As Single
Dim Cincrease(300) As Single, Cdecrease(300) As Single
Dim Fom(300) As Single, K As Single, Ki(300) As Single
Dim A(300) As Single, B(300) As Single, C(300) As Single, Ac_delay(300) As Single, G(300) As Single
Dim P As Single, D As Single, I As Single, Trackutilization_factor(300) As Single, E(300) As Single, F(300) As Single
Set xlapp = New Excel.Application
Set XLBOOK = xlapp.Workbooks.Open("D:\temp\rail2m link\rail segment.xls")
totalrows = Range("A2", Selection.SpecialCells(xlCellTypeLastCell)).Rows.Count
Dim xlsht As Object
Set xlsht = XLBOOK.Sheets(1)
Base_speed = 32.8
Base_blocklength = 1.6
Base_sidespace = 8.82
P = 0
D = 0
I = 1.233

For introw = 2 To (totalrows + 1)
    seg_id = Railroad.seg_id.Value
    Totaltrains_observed(introw - 2) = xlsht.Cells(introw, 23).Value
    length(introw - 2) = xlsht.Cells(introw, 12).Value
    number_tracks(introw - 2) = xlsht.Cells(introw, 5).Value
    Number_signals(introw - 2) = xlsht.Cells(introw, 15).Value
    Number_sidetracks(introw - 2) = xlsht.Cells(introw, 26).Value
    Average_speed(introw - 2) = xlsht.Cells(introw, 28).Value
    'Number_crossings(introw - 2) = xlsht.Cells(introw, 12).Value
    'Number_othrtrks(introw - 2) = xlsht.Cells(introw, 13).Value
    'Number_sidetk(introw - 2) = xlsht.Cells(introw, 23).Value
    'Number_signl(introw - 2) = xlsht.Cells(introw, 15).Value
    If Average_speed(introw - 2) > 70 Then
        Average_speed(introw - 2) = 70
    End If
    A1 = (length(introw - 2) / 12.5) - 1
B1 = length(introw - 2) / 18
C1 = length(introw - 2) / (0.45 * Average_speed(introw - 2))
If A1 > B1 Then
    maximum_triptime(introw - 2) = A1
Else: maximum_triptime(introw - 2) = B1
End If
If maximum_triptime(introw - 2) < C1 Then
    maximum_triptime(introw - 2) = C1
End If

average_blocklength(introw - 2) = length(introw - 2) / (Number_signals(introw - 2) + 1)
If length(introw - 2) < 1 Then
    average_blocklength(introw - 2) = length(introw - 2)
End If
average_sidespace(introw - 2) = length(introw - 2) / (Number_sidetracks(introw - 2) + 1)
If length(introw - 2) < 5 Then
    average_sidespace(introw - 2) = length(introw - 2)
End If
Pispeed(introw - 2) = (Average_speed(introw - 2) - Base_speed) / (0.5 * (Average_speed(introw - 2) + Base_speed))
Piblocklength(introw - 2) = (average_blocklength(introw - 2) - Base_blocklength) / (0.5 * (average_blocklength(introw - 2) + Base_blocklength))
Pisidespace(introw - 2) = (average_sidespace(introw - 2) - Base_sidespace) / (0.5 * (average_sidespace(introw - 2) + Base_sidespace))
If (number_tracks(introw - 2) = 1) Then
    Select Case average_blocklength(introw - 2)
    Case 0 To 3: Foiblocklength(introw - 2) = 1.5379
    Case Is >= 3: Foiblocklength(introw - 2) = 1.1475
    End Case
End Select

Select Case Average_speed(introw - 2)
    Case 0 To 25: Foispeed(introw - 2) = 0.1124
    Case 25 To 32.8: Foispeed(introw - 2) = 0.214
    Case 32.8 To 50: Foispeed(introw - 2) = 0.7062
    Case 50 To 70: Foispeed(introw - 2) = 0.1221
    Case Is >= 70: Foispeed(introw - 2) = 0.4799
End Select

Select Case average_sidespace(introw - 2)
    Case 0 To 15: Foisidespace(introw - 2) = 1.7752
    Case 15 To 21.4: Foisidespace(introw - 2) = 1.9486
    Case Is = 21.4: Foisidespace(introw - 2) = 2.8556
    Case Is > 21.4: Foisidespace(introw - 2) = 0.7897
End Select

Else
    Select Case average_blocklength(introw - 2)
        Case 0 To 3: Foiblocklength(introw - 2) = 1.6122
        Case Is >= 3: Foiblocklength(introw - 2) = 0.8346
    End Select
End Select

Select Case Average_speed(introw - 2)
    Case Is <= 32.8: Foispeed(introw - 2) = 0.1349
    Case Is > 32.8: Foispeed(introw - 2) = 0.3343
End Select

Select Case average_sidespace(introw - 2)
    Case 0 To 15: Foisidespace(introw - 2) = 1.4819
    Case Is = 15: Foisidespace(introw - 2) = 0.626
    Case Is > 15: Foisidespace(introw - 2) = 0.8356
End Select

End If

If (Foispeed(introw - 2) >= 1) Then
    Cispeed(introw - 2) = Foispeed(introw - 2) ^ Pispeed(introw - 2)
Else: Cdspeed(introw - 2) = Foispeed(introw - 2) ^ (-Pispeed(introw - 2))
End If

If (Foiblocklength(introw - 2) >= 1) Then
    Ciblocklength(introw - 2) = Foiblocklength(introw - 2) ^ Piblocklength(introw - 2)
Else: Cdblocklength(introw - 2) = Foiblocklength(introw - 2) ^ (-Piblocklength(introw - 2))
End If

If (Foisidespace(introw - 2) >= 1) Then
    Cisidespace(introw - 2) = Foisidespace(introw - 2) ^ Pisidespace(introw - 2)
Else: Cdsidespace(introw - 2) = Foisidespace(introw - 2) ^ (-Pisidespace(introw - 2))
End If

If (Cispeed(introw - 2) > 0) Then
    Nispeed(introw - 2) = 1
Else: Nispeed(introw - 2) = 0
End If

If (Ciblocklength(introw - 2) > 0) Then
    Niblocklength(introw - 2) = 1
Else: Niblocklength(introw - 2) = 0
End If

If (Cisidespace(introw - 2) > 0) Then
    Nisidespace(introw - 2) = 1
Else: Nisidespace(introw - 2) = 0
End If

If (Cdspeed(introw - 2) > 0) Then
    Ndspeed(introw - 2) = 1
Else: Ndspeed(introw - 2) = 0
End If

If (Cdblocklength(introw - 2) > 0) Then
    Ndblocklength(introw - 2) = 1
Else: Ndblocklength(introw - 2) = 0
End If

If (Cdsidespace(introw - 2) > 0) Then
    Ndsidespace(introw - 2) = 1
Else: Ndsidespace(introw - 2) = 0
End If

Cincrease(introw - 2) = (Ci speed(introw - 2) + Ciblocklength(introw - 2) + Cisidespace(introw - 2)) -
((Nispeed(introw - 2) + Niblocklength(introw - 2) + Nisidespace(introw - 2)) - 1)
Cdecrease(introw - 2) = (Cdspeed(introw - 2) + Cdblocklength(introw - 2) + Cdsidespace(introw - 2)) -
((Ndspeed(introw - 2) + Ndblocklength(introw - 2) + Ndsidespace(introw - 2)) - 1)
Fom(introw - 2) = Cincrease(introw - 2) / Cdecrease(introw - 2)

If (number_tracks(introw - 2) = 1) Then
    K = 0.04538
Else: K = 0.01067
End If

Ki(introw - 2) = K * Fom(introw - 2)

If (number_tracks(introw - 2) = 1) Then
    A(introw - 2) = 973.125 * Average_speed(introw - 2) / (length(introw - 2) ^ 2)
    B(introw - 2) = (67.2765 * P + 151.7085 * D) / length(introw - 2)
    C(introw - 2) = 1.41432 - (maximum_triptime(introw - 2) * 150 / length(introw - 2)) + 150 / Average_speed(introw - 2) + I
    Ac_delay(introw - 2) = (-B(introw - 2) + Sqr(B(introw - 2) ^ 2 - 4 * A(introw - 2) * C(introw - 2)) / (2 * A(introw - 2))
Else:
\[ E(\text{introw} - 2) = \frac{1}{\text{Average}_\text{speed}(\text{introw} - 2)} \]
\[ G(\text{introw} - 2) = \text{maximum}_\text{triptime}(\text{introw} - 2) \times 150 / \text{length}(\text{introw} - 2) \]
\[ F(\text{introw} - 2) = 150 / \text{Average}_\text{speed}(\text{introw} - 2) \]
\[ \text{Ac}_\text{delay}(\text{introw} - 2) = 0.031274 \times \text{length}(\text{introw} - 2) \times Sqrt(E(\text{introw} - 2) \times (G(\text{introw} - 2) - F(\text{introw} - 2) - I - 1.84636)) \]

End If

\[ \text{Capacity}(\text{introw} - 2) = \frac{(\text{Ac}_\text{delay}(\text{introw} - 2) / \text{Ki}(\text{introw} - 2)) \times (100 / \text{length}(\text{introw} - 2))}{\text{Totaltrains}_\text{observed}(\text{introw} - 2) / \text{Capacity}(\text{introw} - 2)} \]

ThisWorkbook.Sheets("rail segment").Cells(introw, "AC").Value = \text{average}_\text{blocklength}(\text{introw} - 2)
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ThisWorkbook.Sheets("rail segment").Cells(introw, "AR").Value = \text{Ki}(\text{introw} - 2)
ThisWorkbook.Sheets("rail segment").Cells(introw, "AS").Value = \text{Ac}_\text{delay}(\text{introw} - 2)
ThisWorkbook.Sheets("rail segment").Cells(introw, "AU").Value = \text{Trackutilization}\_\text{factor}(\text{introw} - 2)

94
ThisWorkbook.Sheets("rail segment").Cells(1, "AC").Value = "avg_bl"
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ThisWorkbook.Sheets("rail segment").Cells(1, "AH").Value = "Pisid"
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ThisWorkbook.Sheets("rail segment").Cells(1, "AJ").Value = "Foibl"
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ThisWorkbook.Sheets("rail segment").Cells(1, "AQ").Value = "Cdsid"
ThisWorkbook.Sheets("rail segment").Cells(1, "AR").Value = "Ki"
ThisWorkbook.Sheets("rail segment").Cells(1, "AS").Value = "Ac"
ThisWorkbook.Sheets("rail segment").Cells(1, "AU").Value = "TUF"
Next introw
introw = 0
For introw = 2 To (totalrows + 1)
If seg_id = xlsht.Cells(introw, 1).Value Then
Railroad.captrn.Value = Capacity(introw - 2)
Railroad.length.Value = length(introw - 2)
End If
Next introw
Railroad.totrs.Value = Totaltrains_observed(introw - 2)
Railroad.speed.Value = Average_speed(introw - 2)
Railroad.blocklength.Value = average_blocklength(introw - 2)
Railroad.sidespace.Value = average_sidespace(introw - 2)
Railroad.maxtriptime.Value = maximum_triptime(introw - 2)
Railroad.nooftracks.Value = number_tracks(introw - 2)
End If
Next introw
EndSub
Maximum Number of passenger and freight flights within the intercity corridor.

To find maximum number of passenger/aircrafts served by each intercity corridor find the ultimate capacity at each airport multiply with the maximum person/freight occupancy per aircraft.

The maximum number of passenger and freight aircraft served by intercity corridor is given as:

\[ C_{\text{passenger}} = \text{Ultimate capacity at Airport A} \times \text{Percent passenger flights in Airport A} \times \text{Percent daily flights from Airport A to Airport B} + \text{Ultimate capacity at Airport B} \times \text{Percent passenger flights in Airport B} \times \text{Percent daily flights from Airport B to Airport A}. \]

\[ C_{\text{freight}} = \text{Ultimate capacity at Airport A} \times \text{Percent freight flights in Airport A} \times \text{Percent daily flights from Airport A to Airport B} + \text{Ultimate capacity at Airport B} \times \text{Percent freight flights in Airport B} \times \text{Percent daily flights from Airport B to Airport A}. \]