May 2018

A PRIORITIZATION MODEL FOR LOCAL ROADWAYS: A CASE STUDY OF SYRACUSE, NY

Kirill Skorokhod
Syracuse University

Abstract

There are many cities like Syracuse that do not have a structured system of managing local roadways. Every city has its own unique way of managing roadways within their boundaries by utilizing different tools. This research focuses on developing a prioritization tool for roadways to help transportation experts prioritize local roads. This tool identifies what roadway segments need to be managed closely under conditions of failure (serviceability limit). For this research, serviceability limit was defined as a condition when it becomes not safe to drive on the road and the only way of improving the road's condition is total reconstruction. The prioritization model includes two analysis methods that generate a list of critical roadways that require the most attention. Currently, many transportation experts who are employed by local authorities utilize ratings from 1 to 10 to identify which roadways should be considered as candidates for reconstruction. A general rule of thumb when utilizing this approach is to include all roadways with a condition rating of 5 and below as candidates for reconstruction.

A database of all roadway segments within the City of Syracuse was obtained from local authorities for this research where a road segment is identified as a portion of a road from one intersection to another. There are approximately 5000 roadway segments in Syracuse making the street prioritization process complex and time-consuming. As a result, a hierarchy of roadway factors was created to better differentiate roadways and produce importance scores for each road segment. The hierarchy includes three major categories of roadway factors: social, economic and environmental. All of the categories were further divided into sub-categories to evaluate every road section. The importance scores generated from the hierarchy were used with the most recent condition ratings to produce a list of the most critical roadway sections. All of the categories and

sub-categories within the hierarchy were assigned weight factors to emphasize what groups of roadway factors have a greater influence on the decision-making process.

Two analysis methods, the first (preliminary) and the second (final), were developed to identify critical roadways using their importance scores and most recent condition ratings. A hierarchy of roadway factors was utilized in both methods to generate importance scores for local roadways. Two methods have some major differences including how importance scores and condition ratings were combined, weights assigned for each category within the hierarchy, and scale values. Top road segments from both methods were compared and showed 24% similarity in results. This means that some of the road sections were identified as critical by both analysis methods even though the analyses have some major differences between two methods. Both prioritization methods were developed based on feedback provided by transportation experts employed by the City of Syracuse.

A PRIORITIZATION MODEL FOR LOCAL ROADWAYS:
A CASE STUDY OF SYRACUSE, NY

by

Kirill Skorokhod

B.S., Syracuse University, 2016

Thesis

Submitted in partial fulfillment of the requirements for the degree of

Master of Science in *Civil Engineering*.

Syracuse University

May 2018

Acknowledgements

I want to thank everyone who has been there for me throughout my academic journey. I would have never been able to be successful in my academic life without help from my family and faculty at Syracuse University.

I would like to thank my graduate advisor, Dr. Baris Salman, who guided me through the graduate school and helped me to achieve my master's degree. Dr. Salman gave me an excellent opportunity to be a teaching assistant that helped me obtain valuable teaching and research experience. I am thankful to my advisor for always being available to help no matter what issue I had or how difficult it was. Additionally, I want to thank a Ph'D student, Song He, who helped me to learn a great deal about conducting research and using engineering software. I appreciate Song's time that he spent with me to share his knowledge. Finally, I express my thanks to the faculty from our department including Dr. Driscoll, Dr. Davidson, Dr. Negussey, Dr. Lui, and Dr. Todorova. I want to thank them for their skillful and interesting teaching methods that helped me to learn necessary engineering skills and obtain essential scientific knowledge.

I express my special gratitude to my family who always believed in me and supported me during difficult times. My parents, Mark and Elena Skorokhod, played a crucial role in building a foundation for my future and helped me to pursue my interests in engineering. I am very thankful to them for always believing in me and giving me everything they could. I am also grateful for experiencing the academic life together with my cousin, Artem Minin, who gave me helpful advices and was a wonderful person to live with during my time at Syracuse University. Finally, I want to express my love and special gratitude to my wife, Anastasia Skorokhod, who has always been supporting me by keeping me motivated and giving me strength to move forward. I am lucky to have such a woman by my side and blessed to have such a wonderful family.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Background

Lifespans of roadways can vary due to a number of factor such as their location, annual average daily traffic (especially percentage of trucks) or pavement type. It is necessary to maintain roads in an adequate condition in order to provide satisfactory performance to roadway users. One of the most significant issues in the management of roads is to identify which roadways are in critical condition and need immediate attention. It is important to know how to properly prioritize roads for rehabilitation or repair when there are thousands of road segments to be managed. In this research, a road segment is defined as a section of a particular road that spans between two intersections. Thus, longer roads tend to have more road segments than shorter roads as in general, they have more intersections with other streets. State departments of transportation (DOTs) usually have organized procedures that they follow to determine if highways need to be renovated or reconstructed. State DOTs can also follow and rely on the research and methods developed by the Federal Highway Administration (FHWA). Unlike the interstate highway programs, authorities of local cities receive limited funds to support their roadways systems and have to distribute these to accommodate the major needs of their cities. Allocation of funds in city budget highly depends on what issues are considered as critical in a particular city. For instance, some cities may have serious problems with sewage or water supply, meaning that those issues will receive more attention and resources than roadway management. As a result, each city depends on its internal resources and professionals to manage their road networks. Moreover, all cities have different decision-making procedures of selecting roadways for rehabilitation and different effectiveness of their road prioritization tools.

1.2 Problem Statement

The process of selection of roadway sections for renovation or reconstruction in cities such as Syracuse is often unclear. Most of the decisions made to renovate roadways are based on the current condition of the roads without a clear structure for other aspects that need to be considered. In many municipalities, road segments within boundaries of a city are assigned rating values from 1 to 10 for condition assessment purposes. One of the main criteria of the decision-making process that is followed by many government authorities is that roadway segments with a condition value below certain rating are considered as candidates for reconstruction. For instance, roadways with a condition rating of 5 and below are candidates for reconstruction in the City of Syracuse. The condition rating of 5 typically means that the distress level on a road is moderate with a frequency of cracks from 25 to 50 percent. A more detailed description of distress ratings will be discussed in the "Methodology" chapter.

There is often no structured decision-making process of determining if a particular road section needs to be renovated or reconstructed making the road selection process highly dependent on personal opinions and experience of city engineers. In addition, many cities have restricted budgets making the cost of roadway reconstruction an important consideration during the road prioritization process. A case study performed in this research analyzed a road prioritization process used by the City of Syracuse. From the database provided by the local authorities of Syracuse City, it was determined that approximately 1836 out of 4898 roadways sections have a current condition rating of 5 or below, suggesting that approximately 38% of all street sections need to be repaired. A well-developed prioritization technique would help transportation specialists to determine the most crucial road sections from those that are identified as candidates for reconstruction based on the condition ratings.

1.3 Research Objectives

This research primarily focuses on the development of a prioritization model that can simplify the decision-making process when selecting road segments for rehabilitation and management. The main objective of this research is to combine the current road evaluation techniques, which mainly focus on the condition of the roads, with new evaluation methods that are based on other aspects associated with roadways and contribute to the overall importance of roads. Local authorities of cities like Syracuse have limited finances that can be applied to road maintenance and do not have a unified methodology to prioritize all roadways. As a result, the decision-making process may be a subject of expert opinion that might be inaccurate due to human error. A prioritization model that can be used by city engineers and other experts as a decision support tool can improve the effectiveness of the road selection process.

Another objective of the research is to build a new prioritization model based on a large database of almost five thousand road segments that was obtained from the City of Syracuse containing a significant amount of information regarding each street. An ArcGIS file containing information about each road section was utilized in combination with the database to evaluate road segments and create the prioritization model. The primary focus of the prioritization model developed in this research is to provide guidance for the local transportation experts by identifying roadway segments that require the most attention not only in terms of current conditions but also in terms of various factors presented in the hierarchy developed in this research.

Chapter 2

Literature Review

2.1 Overview

Rapid growth and development of the roadway infrastructure leads to larger road networks that need to be maintained and higher maintenance expenses to keep them in adequate condition. Limited funds and higher numbers of deteriorated roads require experts to be careful when allocating resources for road reconstruction. As expenses to keep roads in adequate condition increase, it is important to disburse limited funds carefully and efficiently. In a study written by Gupta, Kumar and Rastogi (2011), the authors emphasize the importance of efficient allocation of limited funds due to increased challenges in maintenance and rehabilitation of roadway infrastructure. There are a number of techniques that are widely used in prioritizing roads based on aspects such as pavement condition or volume of daily traffic. Even though most of the prioritization methods to evaluate roadways primarily focus on the types of distresses that are present on the pavement surface and their severity, some of the techniques discussed further include other factors such as traffic load, geographic aspects and cost-effective treatment options.

2.2 Transportation Asset Management (TAM)

There is no single definition that describes transportation asset management due to its complexity. Henry Kiwelu Meleki (2009) describes the depth and different levels of asset management applications in the transportation industry. One of the definitions of Transportation Asset Management (TAM) provided in the research study is that it "*consists of business* *methodologies that assist managers to organize and strategize, plan and implement goals and objectives through the use of economic, accounting, and engineering analytical tools*." Meleki states that asset management methodologies in civil infrastructure are a relatively new concept that was adopted from private organizations. Also, private companies use asset management techniques to minimize their expenditures and maximize the return on investments.

Another definition of TAM is presented in American Association of State Highway and Transportation Officials (AASHTO) Transportation Asset Management Guide (2017) where it is defined as *"a strategic and systematic process of operating, maintaining, upgrading and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision-making based upon quality information and well-defined objectives*." AASHTO specifies that the main goal of the TAM model is to minimize the life-cycle costs for managing and maintaining transportation assets such as roadways, railroads, bridges, tunnels and various roadside features.

Even though asset management is broadly implemented by private businesses, according to Acharya (2014) most transportation agencies and state departments of transportation in the United States are still struggling to determine what asset management means to them and are tentative as to whether this is an approach they want to adopt. There are three general approaches that can be used to value transportation assets: economic value, historical cost, and current replacement cost. The economic value describes how valuable a particular asset is to the community in terms of its efficiency in moving people and goods. The historical cost is the initial cost to build the facility in the year it was constructed. Finally, the current replacement cost is the engineering cost estimate to replace the facility under current market conditions with one of equivalent capacity, taking into account cost efficiencies arising from improvements in technology (Acharya, 2014). The asset valuation methods described by Acharya (2014) will be partially integrated in the prioritization model for this research study as parts of the social, economic, and environmental groups.

2.3 Pavement Management Systems

Pavement Management Systems (PMS) offer a road prioritization tool that not only focuses on road conditions but may also include a number of other aspects related to road sections. Pavement Management Systems can be defined as various integrated systematic methods for the selection of the treatment and maintenance necessities, determination of the priorities, and the optimum treatment time through predicting the future pavement conditions (Shahin, 2005). PMS is highly important to find cost-effective solutions for road maintenance taking into account the limited resources that are available to the transportation authorities. According to a recent research study conducted by Fakhri and Dezfoulian (2017), there are three generations of decision support systems that have been incorporated in various pavement management systems in the past. All three generations feature prioritization techniques that evaluate different aspects of prioritization methods. The first generation of decision support systems primarily focuses on the current condition of the roads and the cost of rehabilitation. The second generation of decision support systems incorporates predicted future conditions and costs of rehabilitation in addition to the current factors. Finally, the third generation of decision support systems evaluates the life-cycle costs of street sections for agencies and users (Fakhri and Dezfoulian, 2017).

In addition, PMS can focus on different evaluation criteria depending on what generation of decision support systems is incorporated within them; therefore, they follow specific prioritization models that vary from one generation of decision support systems to another. Prioritization methods used for the three generations of decision support systems and their differences are summarized in Table 2.1. It was also stated that one of the most essential components of a successful pavement management system is a pavement deterioration model that evaluates the following aspects: rate of asset degradation, remaining service life, and road user costs (Gupta et. al, 2011).

Table 2.1: Prioritization Methods of Pavement Management Systems (Robinson et al. 1998)

	Generation of Decision Support Systems		
	First	**Second**	**Third**
Prioritization Method	Ranking based on function of present cost, condition and road hierarchy	Ranking based on cost-effectiveness, with consideration of treatment life, and analysis of deferment options	Formal optimization of multiple treatment options per section over a multi-year period

Authors of the "Environmentally Preferable Pavement Management Systems" study conducted in 2013 concluded that "*PMSs aim to optimize the balance of preventative and restorative treatments over time in order to maximize the return from the maintenance investments.*" They also stated that pavement management systems have evolved significantly in order to "*address some of the previous shortcomings in maintenance planning and ideally maximize the condition of the pavement network over the long term within available budgets.*" A variety of PMSs were incorporated in the previously mentioned study by building a Genetic Algorithm (GA) framework. Some of the environmentally preferable PMSs used by pavement managers include evaluation of pavement conditions, deterioration models and Global Warming Potential (GWP). Each of those methods has different trade-offs between GHG emissions, cost, and network performance (Goose et al. 2013).

2.4 Pavement Condition Assessment

Pavement Condition Assessment (PCA) focuses primarily on the condition of the roads and helps to determine which roads require more immediate attention than others. Pavement Condition Assessment is performed by evaluating a roadway based on a variety of factors such as surface deterioration, pavement deflection, rut depth, roughness, and skid resistance (Haas et al. 1994). PCA is one of the most important components in the decision-making process and is an essential part in prioritization of road maintenance (Sun and Gu, 2011). The main logical aspect that is followed by the PCA approach is to assign ranking values to roadways based on a number of applied index factors. In order to rank roadway sections using this method, each street needs to be assigned a combined index value that is equal to the sum of all individual indices where each individual index is derived by multiplying its weighting factor by its value (Shahin and Kohn, 1979). A disadvantage of using solely the PCA method is that the performance indicators used for assigning index values to roadways are not always consistent for all analyzed road sections since some indicators require subjective opinions of transportation experts. Nevertheless, rating roadways based on their pavement conditions is a direct approach that primarily takes into account physical condition of the pavement and is one of the most commonly employed methods in evaluating and prioritizing streets that require rehabilitation or reconstruction.

2.5 GIS Applications in Road Management

Geographic information systems (GIS) are used in many different applications as they help to better organize, analyze, and visualize spatial data. GIS is one of the main tools that is used in this research due to its convenient data analysis and conversion capabilities. GIS is widely used in transportation applications to help with analysis such as budget distribution, determination of road maintenance techniques, pavement condition assessment, and generation of prioritization models. Shrestha and Pradhananga (2009) utilized ArcGIS software to develop a spatial maintenance prioritization tool for road networks. The main road factors that were considered were: traffic counts, pavement conditions, maintenance costs, and alternative roadways available. Geographic information systems have also helped to develop other software programs that aid to manage traffic, road conditions, and safety data (Shrestha and Pradhananga, 2009). Bham and Darter (2001) used traffic data, rehabilitation and pavement condition criteria in a GIS to create a predictive model for optimum pavement maintenance.

Even though GIS is used to evaluate several decision-making factors in road management and prioritization processes, one of the most commonly analyzed decision influencing factors in transportation is budget. Most of the transportation agencies in the United States work within limited budgets allocated for transportation needs, making it the main restricting factor in selecting projects and management techniques that could be used. Assaly et al. (2005) utilized GIS to evaluate roads based on the available capital developing a decision support system for highway capital planning in Alberta, Canada. The main roadways factors that were considered were traffic volume, collision records, level of service, and available roadway information such as speed limit, pavement type, and number of lanes. Pietrzycki (2014) combined the hierarchy model and a tool within the GIS called ModelBuilder to help decision makers to identify and prioritize which roads need to be repaired within a given budget amount. Based on the GIS analysis of road segments of Toledo, OH, this model was used to select appropriate repair and treatment techniques for the streets that required the most attention. One of the most useful features of GIS that sets it apart from other older methods is its visualization capabilities (Pietrzycki, 2014).

In addition to budget constraints, the current condition of roadways is another highly influencing factor that can be evaluated with GIS applications. Some research studies implementing GIS features focused primarily on the pavement condition of roadways. For instance, roads can be analyzed using GIS features based on three characteristics: visual ratings, surface index and rut depths (Pratap et al. 2006). This approach focuses on functional and structural pavement conditions in order to develop a strategy that utilizes the most appropriate pavement rehabilitation and maintenance techniques.

2.6 Hierarchy Development in Road Prioritization

Many studies have been conducted where hierarchies of road factors were developed in order to generate prioritization models based on road features of interest. Researchers develop hierarchies of factors and incorporate them in the AHP process. The Analytic Hierarchy Process (AHP) was developed by Thomas L. Saaty in 1971. The AHP is a theory of measurement through pairwise comparisons and relies on expert judgement to derive priority scales (Saaty, 2008). AHP is used to consider relative importance within categories of a particular hierarchy as well as ranking categories and subcategories within the hierarchy by performing pairwise comparisons. During the pairwise comparison process, elements of the hierarchy are evaluated depending on how both activities contribute to the ultimate objective of the hierarchy. Pairs of elements can be assigned values on a scale from 1 to 9 where 1 means both activities contribute equally to the objective and 9 means the evidence favoring one activity over another is of the highest possible order of affirmation (Saaty, 2008).

Sun and Gu (2011) conducted a study where a hierarchy of road factors was built to prioritize road segment where conditions affecting road performance such as surface deterioration, deflection index, rut depth, roughness and friction coefficient were used as criteria in the hierarchy. The ultimate goal of the analytical hierarchy process in this study was to classify each road segment into an assessment category by performing pairwise comparison of the factors and assigning ranks to roadway sections.

In some of the previous works in this area, researchers developed hierarchies to incorporate a wide variety of aspects related to road segments. For instance, Dalal et al. (2009) incorporated four roadway categories that were divided into social, economic, demographic and infrastructure groups, which affect the prioritization process (Dalal et al. 2009). This work is a great example illustrating how the effects of several factors can be considered in the decision-making process in road prioritization in addition to budget constraints and pavement conditions. Another aspect that can be considered in roadway prioritization techniques is sustainability of selected methods. Some of the developed sustainability-related road management tools include Greenroads, GreenLITES, and InVEST. These tools can be used to evaluate sustainability of selected options and can be incorporated in decision-making processes to produce more environmentally friendly solutions.

Pietrzycki (2014) incorporated different road criteria in the analytical hierarchy process. The problem statement Pietrzycki's study states that the decision-making process of selecting roadways for repair and reconstruction in the City of Toledo primarily depends on an engineer's opinion. The research performed for the City of Toledo is very relevant my thesis because the author identified the main problem as an unclear decision-making process in prioritization of local roads. Therefore, Pietrzycki (2014) aimed to develop a support tool to help engineers prioritize local roadways more effectively. Pietrzycki (2014) focused primarily on the budget distribution for road repair of the City of Toledo where engineering factors such as road condition, traffic volume and utility presence were incorporated into the hierarchy developed. After developing the hierarchy, weighting factors based on expert opinion were assigned to categories and their sub-categories to show the superiority of some factors over the others in the decision-making process for road prioritization. It is important to note that weighting factors describing importance of road factors in that study had a sum of 1 within each category.

Unlike the prioritization tool developed by Pietrzycki (2014), which focused primarily on the allocation of a specific city's budget, the risk-based prioritization model proposed in this research study incorporates social, economic, and environmental factors to evaluate local roadways as well as their condition ratings. Currently, there have only been a few road prioritization models developed to help cities efficiently select roadways for repairs. Therefore, developing new prioritization models can greatly improve efficiency of the road selection process for repair and help cities to allocate limited resources more efficiently.

Chapter 3

Methodology

3.1 Methodology Overview

Some of the commonly used tools in building a roadway decision-making methodology are Microsoft Excel and ArcGIS. Excel is a well know software that is used to analyze sets of data as well as store and organize information. Excel was one of the major tools utilized for this research to store all of the data and organize it to assess developed prioritization techniques. ArcMap software is another tool that was used to analyze roadway sections in the City of Syracuse that allowed visual representation of the acquired data and helped to simplify the process of differentiating roadway segments. In addition to the tools mentioned, a hierarchy of road factors that can affect the decision-making process was developed to better visualize and organize all of the prioritization criteria.

3.2 Generating a Hierarchy

All major factors that influence a decision-making process have to be taken into account in order to produce an accurate prioritization tool. After analyzing many aspects that can relate to every road, it was decided to produce a hierarchy of all decision-influencing factors grouped into three main categories. The prioritization hierarchy model combines the following parameters in order to properly evaluate road sections: the roadway importance and the current condition of the road. The main purpose of evaluating the importance of road sections is to determine the severity of consequences if a particular road segment fails. The “current condition” parameter is another part of the road prioritization analysis that addresses the questions how adequate the road service is and how likely it is to fail.

The first major category created for the analysis of roadways is the importance level that can be assigned to each road segment. The importance level includes three major categories that group road parameters based on the Triple Bottom Line of Sustainability (TBL or 3BL). The TBL structure includes social, economic, and environmental factors that are used to categorize and evaluate roadway sections. Further, each major category includes sub-categories to provide more depth to the considered factors. It should be noted that roads evaluated by this method do not include interstate highways because usually State DOTs are responsible for managing them. However, evaluated roads may include state routes if city authorities are responsible for managing them.

3.3 Social Factors

The first category addressing the importance of a particular road section includes social aspects of roads. The social aspects were divided into three sub-categories: road functional classification, proximity of roads to important objects, and the population density of neighborhoods where the roads are located. Those sub-categories are described further in this section with the aim to represent the importance of a particular road segment. A general overview of social categories that are considered when evaluating local road segments is provided in Figure 3.1.

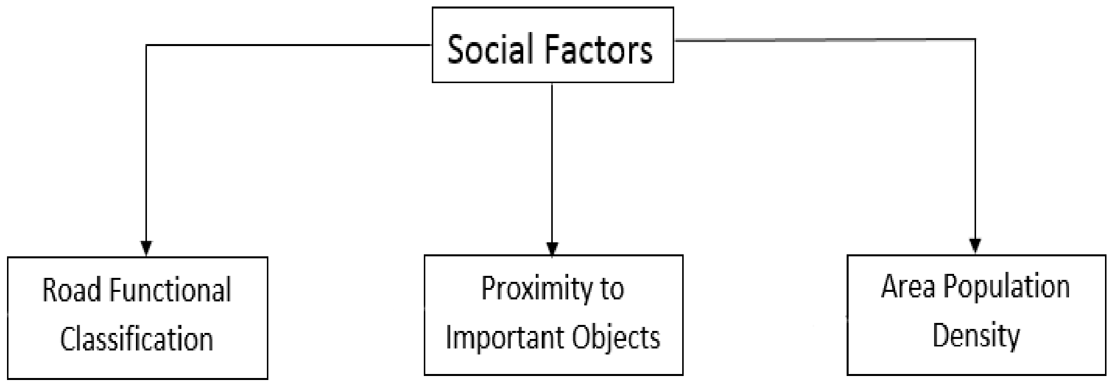


Figure 3.1: Social Categories of Roadway Factors

3.3.1 Road Functional Classification

Road functional classification is an important parameter that helps to identify urban area layouts and determine volume of daily traffic each road can carry. In addition, maintenance-related activities such as snow plowing and clearing debris are also captured by road classifications since it is very important to make sure that higher class roads (arterials, major collectors) are free of problems. Every country has a unique categorization type for grouping roads based on their functional class. In the United States, road functional classification was defined by the Federal Highway Administration (FHWA) as "*the process by which streets and highways are grouped into classes, or systems, according to the character of traffic service that they are intended to provide.*" Urban roads in the US can be categorized as arterial roads, collector roads, and local roads (Figure 3.2). Furthermore, arterial roads can be divided into principal arterial and minor arterial roads while collector roads can be divided into major collector and minor collector roads (FHWA, 1989).

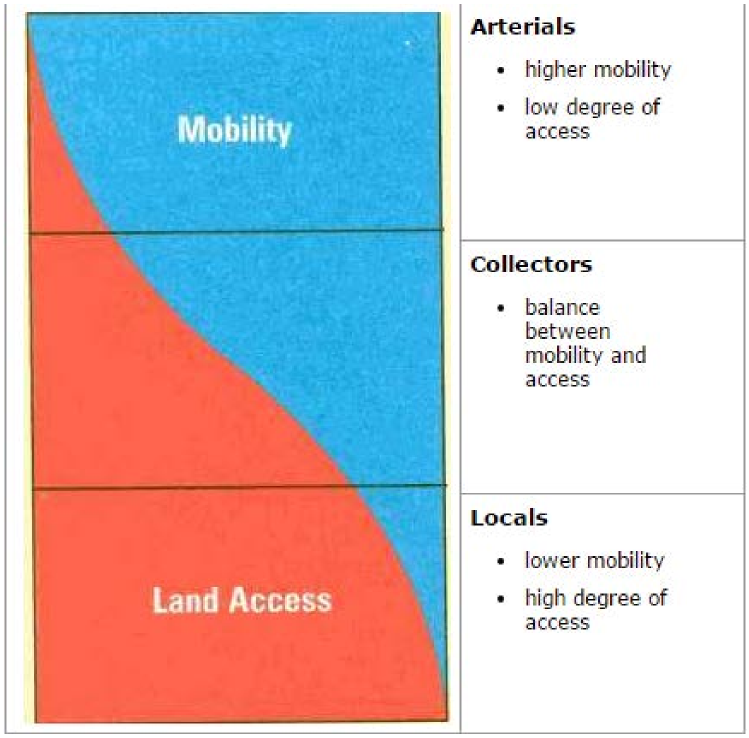


Figure 3.2: Comparison of Road Classifications Based on Their Mobility and Land Access (FHWA, 1992)

In the analysis performed for this research, local city roadways were grouped into four common functional classes: primary arterial, minor arterial, collector and local roads. Collector roads were not divided into major and minor groups since the difference in traffic was considered negligible between the two types. In general, the main differences between the urban road classes are the volume of traffic, levels of mobility, and degree of access. Arterials are usually roads with high mobility and low accessibility that carry large volume of traffic. On the other hand, local roadways usually have lowest mobility with the highest degree of access. Finally, collector roadways provide a balance between mobility and accessibility for traffic. A more detailed description of functions that each road type provides is presented in Table 3.1 where road classes are compared on the basis of access to land, mobility/travel speed allowed, travel distance served, and service to through traffic movements (FHWA, 1989).

Table 3.1: Comparison of Functions Provided by Different Road Classes (FHWA, 1989)

Functions	***Principal Arterials***	***Minor Arterials***	***Collectors***	***Local Roads***
Access to land	Discouraged	Subordinate	Provide	Primarily
Mobility/Travel speed	Highest	High	Low	Lowest
Travel distance served	Long	Moderate	Short	Shortest
Service to through traffic movements	Primarily mobility	Mobility	Accessibility	Primarily Accessibility

3.3.2 Proximity to Important Objects

The second sub-category under "social importance" is the proximity of roadways to important objects. The proximity to critical and public objects is considered as an important factor because the roads around these objects can serve as detour routes if the primary routes fail or undergo reconstruction. The hierarchy produced in this research divides objects in this sub-category into two groups. The first group includes objects that serve critical roles in uninterrupted operation of cities. Critical facilities were defined by Federal Emergency Management Agency (FEMA) as facilities that provide essential services to a community during or after the occurrence of a disaster. Facilities that are considered as critical are defined by FEMA (2015) on their "Critical Facilities and Higher Standards" fact sheet. Therefore, proximity of roadways to the following critical objects is evaluated in this study: medical facilities, fire stations, police stations, schools, water supply/treatment plants and power generators. Another object type considered for this sub-category consists of public objects that are expected to receive high volume of pedestrian and vehicular traffic during peak hours. These public objects include malls, universities, train stations, regional transportation centers, and stadiums. In addition to the public objects provided, top employers in a city of interest can be identified, and buffers could be created around their main facilities. It was decided to include facilities of the top employers because most of them serve as public gathering points not only for employees but also for their customers. If a facility of one of the top employers is classified as a critical facility, it is not double counted in the analysis (ex. some hospitals in the area).

3.3.3 Neighborhood Population Density

The final sub-category under the social importance of roadways is population density of the areas where the road segments are located. It is a significant aspect of the prioritization tool because number of local residents affected in case of a roadway failure will depend on the population density in the neighborhood and the location of the area within the city of interest. In addition, the results will depend on the information available for a particular city. Although there are many options to determine neighborhood locations of road segments, one of the tools that could be utilized is ArcGIS, which is described further for this research in the "Syracuse Case Study" chapter.

3.4 Economic Factors

In general, roadways are structured into three main layers that serve different purposes and have different depths. Most of the roads consist of subgrade at the bottom followed by subbase/base in the middle and pavement at the top. Pavements are divided into two broad categories: flexible pavements and rigid pavements. The most commonly used type of flexible pavements is asphalt (bituminous concrete). Asphalt pavements allow plastic deformation, which is transferred to other subsequent layers. Rigid pavements are usually made of concrete slabs that distribute the load over a large area underneath them. The distribution of the wheel load when applied to flexible and rigid pavement types is illustrated in Figure 3.3.

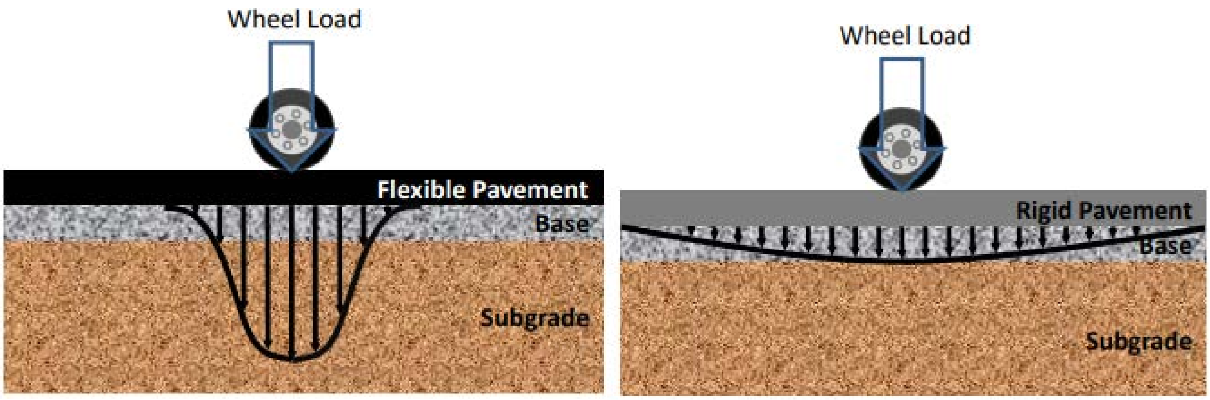


Figure 3.3: Distribution of Load in Flexible and Rigid Pavement Types (FHWA, 2017)

Many roadways in cities like Syracuse have a flexible pavement design due to its lower initial construction cost when compared to rigid pavements. In the flexible pavement design, the upper pavement layer consists of surface course (wearing course) on top and binder course underneath. Wearing course is a thin layer that protects the layers underneath from being damaged and provides an adequate friction for a safe driving experience on the road. The binder course is used to adequately connect (bind) the surface course to the base. The required depth for the surface course or wearing course is typically from 1 to 3 inches while the required depth for the binder course can vary between 2 and 4 inches. In addition, the minimum required depth for the base and subbase course is 6 inches (Rouphail, 1985). In some cases, roadways lack the subbase or base layer as only one of them is used in a pavement design to transfer the load to the subgrade (Kruntcheva et al., 2005). In some cases, the roads that have a flexible pavement design can have a concrete base to support the asphalt pavement on top. A typical roadway cross-section representing the flexible pavement design with surface course, binder course, base subbase, and subgrade layers is shown in Figure 3.4.

The main economic factor that affects the importance of roads is the cost of reconstruction in case a road reaches it serviceability limit. Roads with higher reconstruction costs are considered to be more critical than roads with lower reconstruction costs. The main logic behind this assumption is that emergency contracts usually cost more than planned activities. For streets with high reconstruction costs, negative impacts of emergency contracts can be even more significant.

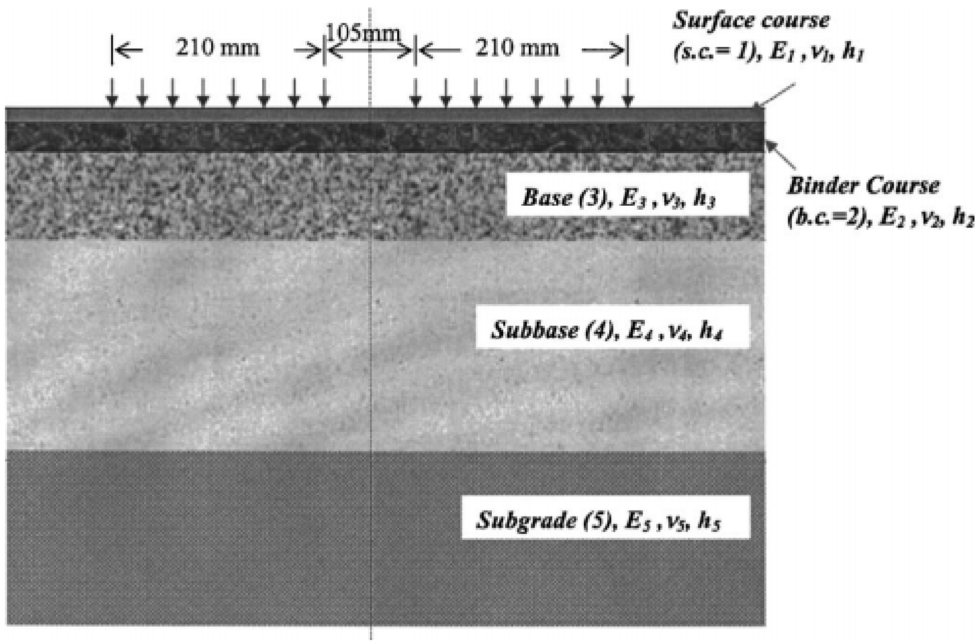


Figure 3.4: Layers of a Typical Flexible Pavement Design (Kruntcheva et al., 2005)

As a result, unexpected failures of more costly roads will have higher economic impacts on city budgets. The cost of reconstruction depends on a variety of factors such as length and width of the road, composition of pavement layers, and depth of each pavement layer. As a result, the economic aspects category of the hierarchy does not include sub-categories, as the main decision-influencing factor is the cost of reconstruction in case when a road reaches its serviceability limit. It should be noted that pavement types that are present in cities will differ based on a variety of factors such as location and available budgets for maintenance.

3.5 Environmental Factors

Environmental impacts of roads are a very complex issue due to uncertainties involved in the evaluation process. Roadways can have different designs and life expectancies with a large variety of possible environmental impacts. In addition, there are many aspects that have an impact on the environment with some uncertainties over how they can be estimated. A common approach to evaluate the impacts of roads on the environment is by Life Cycle Assessment (LCA), which is used to quantify materials and energy flow throughout the life cycle of roadways. Life Cycle Assessment is a tool which makes it possible to assess the environmental impacts of a product, a process or an activity, through identifying and quantifying the flows of energy and materials; evaluating the consumption of energy and materials as well as emissions generated; and identifying and evaluating possible measures for improving the environment (Stripple, 2001). Another definition of Life Cycle Assessment states that LCA is a methodology to evaluate the environmental impacts of a product over its life cycle, i.e. from material extraction to the end of life disposition (Santero et al., 2010). A basic LCA model includes three stages that describe a flow of energy and materials: inputs, system boundary and outputs. The raw materials and energy flow that serve as inputs in the system when road LCA is evaluated is illustrated in Figure 3.5. Then, the energy and materials are used to acquire raw materials and used to manufacture the required products/resources. After manufacturing, new products are used, reused and maintained throughout their lifecycle. Finally, the products are recycled or disposed at the end of their lives. When evaluating environmental impacts, outputs of the system are the end products that have impacts on the environment. Outputs of the system most commonly include emissions, solid wastes, coproducts, waterborne wastes and other releases that are the results of the "input" and "system boundary" stages.

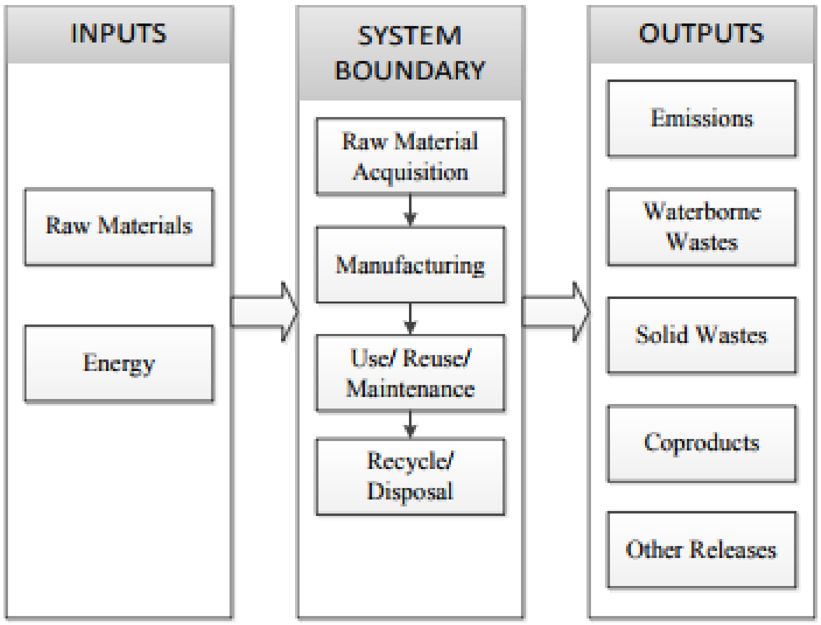


Figure 3.5: Life Cycle Assessment Stages (Hendrickson et al., 2006)

In order to evaluate existing roadways, it is important to understand how different pavement types and road functional classifications affect the environment. Almost 83% of all roads and streets in the United States are made of asphalt wearing surface, whereas only 7% are rigid concrete surface and approximately 10% are made of composite type (bituminous surface on PCC base) (Horvath and Hendrickson, 1998). Even though Life Cycle Assessment can be a complicated method that evaluates the entire lifespan of roadways, it can be useful in assessing environmental impacts of the total asphalt reconstruction procedures when a roadway reaches its serviceability limit. The environmental importance categories that were selected in this research to prioritize road sections are shown in Figure 3.6.

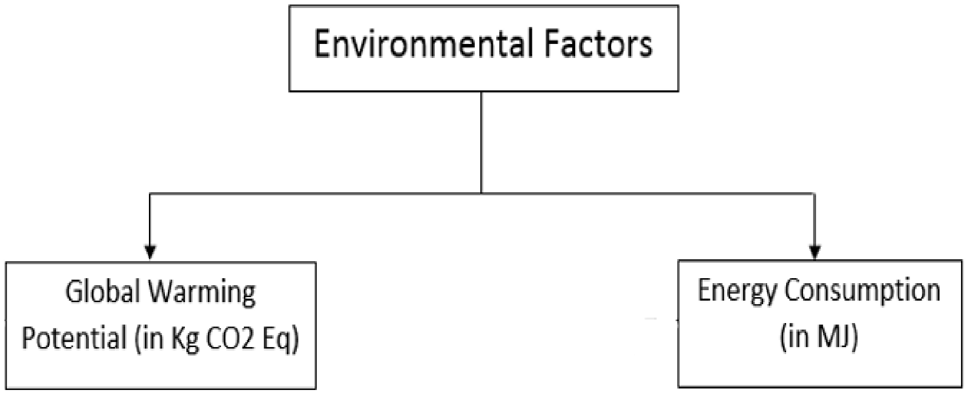


Figure 3.6: Categories of Environmental Factors

3.5.1 Global Warming Potential of Road Reconstruction

One of the possible options to estimate environmental impacts of a total roadway reconstruction is by estimating its Global Warming Potential in kilograms of carbon dioxide equivalent (Kg CO2 Eq). Carbon dioxide is the most common type of greenhouse gas that is released to the atmosphere by human activities. As a result, all of the other greenhouse gases such as methane and CFCs can be converted into carbon dioxide equivalent amounts in order to make the estimation uniform among all greenhouse gases.

There are many techniques that are used to prevent a roadway failure with different cost ranges and amounts of materials involved. In addition, roadways can be grouped by their road type classifications to determine their environmental impacts since they provide services for varying volumes of traffic. Salem (2014) analyzed the most commonly used maintenance, repair and rehabilitation (MRR) techniques to determine their corresponding Global Warming Potential over the design life of a pavement, which is expressed in kg of CO2 eq. According to that study, the total asphalt reconstruction produces the highest level of CO2 emissions for a roadway over its design life and may be avoided by selecting an appropriate MRR technique. Also, additional environmental impacts such as higher fuel emissions can occur when roads are closed for re-construction. This kind of impacts will probably be higher if roads closed are major roads (ex. primary arterials). This criterion is captured by the road functional classification sub-category discussed previously.

3.5.2 Energy Consumption during Road Reconstruction

Another possible option to evaluate environmental impacts of the total pavement reconstruction is by analyzing how much energy is consumed during the design life of roadways. Energy consumption is one of the factors that contributes to the global warming; nevertheless, it can be assigned as another sub-category for environmental importance of road segments. In addition to contributing to global warming, the energy consumption may include a variety of other environmental impacts such as depletion of resources or unsustainable techniques for their extraction. Salem (2014) also analyzed how much energy is consumed in megajoules over the design life of a pavement when different MRR techniques are used. As it was observed previously, the total asphalt reconstruction consumes the most energy over the design life of pavement since it is the most fuel and resource intensive technique. In addition, total reconstruction is considered to be an ultimate measure and performed only once over the pavement design life. On the other hand, other MRR techniques are usually performed more than once over the design life of a pavement to extend its service life.

3.6 Current Conditions of Road Segments

After the hierarchy that evaluates the importance of each roadway segment within the database has been set up, the second part of the evaluation technique can be assessed in order to complete building the prioritization tool. The second portion of the prioritization tool focuses on the current condition of the road segments that are analyzed in this research. Evaluating the current condition of streets is an important aspect for road prioritization since it is the most direct method to determine if a specific road segment is a candidate for a MRR technique. The most common way to assess the condition of roads is by a visual inspection where field engineers visually examine roadways and evaluate their level of distress.

There are many types of distress that can develop on roadways and affect different parts of a roadway segment. Rigid and flexible pavements may have different distress types. Blowups or popouts are more likely to develop in concrete pavements while distresses such as bleeding and rutting are more commonly observed in flexible pavement types. It is possible to group all distresses for flexible pavement types into five categories: cracking, patching and potholes, surface deformation, surface defects, and miscellaneous distresses (FHWA 2003). The following table (Table 3.2) summarizes all of the distress categories with their most common types grouped together.

Even though many types of distresses can be present on a pavement simultaneously, most of the existing methods of distress identification and assessment focus primarily on only one category, which is cracking (Maeda et al., 2017). Most of the time, road inspectors visually assess road conditions and record the severity of cracking on a particular road without evaluating other distress types making the cracking category more important. As a result, cracking distress is considered as the major factor affecting the roadway condition since this is what is visually inspected and recorded.

Table 3.2: Distress Categories of Flexible Pavements (FHWA, 2003)

Distress Category	**Distress Name**
Cracking	• Fatigue Cracking • Block Cracking • Edge Cracking • Longitudinal Cracking • Reflection Cracking at Joints • Transverse Cracking
Patching and Potholes	• Patch Deterioration • Potholes
Surface Deformation	• Rutting • Shoving
Surface Defects	• Bleeding • Polished Aggregate • Raveling
Miscellaneous Distresses	• Lane-to-Shoulder Dropoff • Water Bleeding and Pumping

In addition to cracking distress and patches, the overall condition ratings that were assigned to roadway segments may include other distress types such as surface deformation, surface defects, and miscellaneous distresses. In order to assess the road segments based on their current condition, it is important to follow a consistent logic that is as inclusive as possible where all distress types are considered. As a result, the roadway segments provided in the database will be evaluated based on the most recent overall condition values that consider all of the distress categories that may be present on the streets. In addition to the hierarchy analysis, the road segments are also prioritized based on their current condition ratings, meaning that the roads with the highest levels of distress (lowest overall condition ratings) are among the strongest candidates for renovation or reconstruction.

3.7 Methodology Overview

In summary, all of the roadways segments in this research are prioritized based on two major aspects: the importance of the road segments and the current condition of the roadways. The importance hierarchy of roads created for this research describes the consequences of a roadway failure based on three main groups: social, economic, and environmental factors.

Social factors mainly focus on the value of roadway segments for the community and are characterized based on three criteria: road functional classification, proximity of streets to important facilities, and the population density of the neighborhood where the roads are located. Economic factors focus on the cost of the pavement reconstruction in cases when roads reach serviceability limits and include the estimation of the reconstruction cost for major pavement types that are present in a city of interest. The final group of factors focuses on environmental factors that help to assess the roads based on their contribution to global warming and the amount of energy released if any of the roadways fails and has to be reconstructed.

After all of the road segments are prioritized following the factors presented in the hierarchy, evaluation is done jointly based on their importance and condition ratings. After the importance score and the current condition rating have been identified for every road segment, a list of most critical road sections can be produced based on two different analysis approaches described in the “Analysis and Results” chapter.

Chapter 4

Syracuse Case Study

4.1 Hierarchy of Syracuse Roadways

After the methodology was established, it was applied to local roadways in Syracuse (NY) to generate and evaluate results of the analysis. Roadway segments within the boundaries of Syracuse were evaluated based on the information obtained from Office of Innovation of the City of Syracuse. In order to evaluate road sections based on the factor groups described in the previous chapter, Excel and ArcGIS files containing information about roadways of Syracuse were used. The excel worksheet was used to obtain necessary information about road parameters and functional classifications. The ArcGIS file was used to create buffers, identify relevant road ID numbers and highlight roads of interest. In addition, outside sources including guides and web sources were extensively used to find required information about population densities, reconstruction costs, and environmental impacts. All of the sub-categories and value ranges developed for the factor groups within the hierarchy are based on the relevant information and may vary for other cities.

4.2 Evaluation of Social Factors

Using the approach described in the previous chapter, social importance of roadway sections in the City of Syracuse was analyzed based on the following categories: traffic volume roadways carry (functional classification), proximity of roadway segments to important objects, and population density of neighborhoods where roads are located. Most of the cities have four types of road functional classes. In The City of Syracuse, approximately 5.8 % of all roads are principal arterials, 18.2 % are minor arterials, 7 % are collectors, and the remaining 69 % are local roads. This information was used to evaluate roadways under the "Road Functional Classification" sub-category. The description of the information used for the "Proximity to Important Objects" and "Area Population Density" sub-categories is provided in the following sections.

4.2.1 Proximity of Roadways to Important Objects in Syracuse

In order to determine roadways with close proximity to critical and other important public objects, ArcGIS software was utilized. A shapefile containing roadways that were analyzed in this study was uploaded to ArcGIS where each road segment contains a unique ID number in addition to its detailed description. Then, locations of all important objects mentioned above were identified and located on the shapefile. Circular buffers with a radius of 1000 feet were created around important objects described previously and roadways located within those circular areas were highlighted. All of the roadways segments within the areas of buffers were considered to be in the close proximity to important objects and moved to a new layer. The selected roadway segments were grouped into clusters based on what type of facilities or services they are in the close proximity of and assigned different colors. For instance, buffers containing roadways in the proximity of medical facilities were colored in blue and are presented in Figure 4.1. Buffers representing locations of all other important objects can be found in Appendix A**.**

It should be noted that some of the buffer zones overlap due to presence of several critical objects in a particular area. After all buffers were created, roadway segments within buffer areas were identified based on their unique identification numbers stored within the ArcGIS shapefile. Road segments were assigned ratings in the hierarchy based on the number of critical objects they are in the close proximity of, since some roadway segments were in the proximity of several critical and other important public objects. Selected road segments were moved to an excel file so that they could be used to locate required segments in the entire database of roads utilized in this research. In addition, all of the information regarding the names of the largest employers in Syracuse is provided in Appendix A (Table A-1). Since some of the top employers had several facilities or main facilities located outside Syracuse, only facilities of the top employers located within borders of the City of Syracuse were used in the analysis.

Figure 4.1: Buffers Indicating Locations of Critical Medical Facilities in Syracuse

To summarize the second sub-category under the social importance group, the following critical services within the City of Syracuse area were found for the research: thirty-two public schools, nine fire stations, five medical facilities, four police stations and three water supply/treatments stations. In addition to critical objects, other important facilities used for this research include two stadiums, one major regional transportation center, one train station, one mall, two universities, and those locations of top employers that have not been already included in any of the previous categories. The size of buffers was selected to be 1000 feet due to the size of the City of Syracuse where larger or smaller buffers would include too many or too few road sections as well as create may overlaps with other objects.

4.2.2 Neighborhood Population Densities in Syracuse

The population in Syracuse has been somewhat stable throughout the last seven years since the number of people living in the City of Syracuse has only changed by 1.3 percent. According to the US Census Bureau, the population of Syracuse has decreased from 145,170 in 2010 to 143,378 in 2016. The City of Syracuse consists of eight major areas: Northside, Eastwood, Eastside, Valley, Southside, Lakefront, Downtown and Westside (Figure 4.2). All of these areas have varying population densities depending on the location and the size of a particular city area. Areas with the highest population density include Northside, Southside and Westside where population densities are above 10 people per acre. Those areas are followed by Eastwood, Eastside and Downtown with population densities between 5 and 10 people per acre. Valley and Lakefront are two remaining areas with the least population and have population densities that are below 5 people per acre mark (Table 4.1). Population density data are used to assign different levels of importance to roadway segments when neighborhood areas are compared with each other and do not represent exact population of the areas in 2017. The data from 2010 is considered accurate for those goals since the population of Syracuse have remained almost unchanged throughout the previous seven years.

Table 4.1: Population Density of Syracuse Areas (Syracuse Government, 2011)

Area	2010 Population	2010 Persons/ Acre
Northside	38,928	15.7
Eastwood	10,724	9.1
Eastside	27,618	6.4
Valley	8,422	3.8
Southside	34,321	14.2
Lakefront	579	0.4
Downtown	1,879	6.0
Westside	22,697	11.5

All of the eight areas within the City of Syracuse were located and identified using ArcGIS. The original ArcGIS map file of Syracuse was used to create an individual layer for each city area. Every area section was assigned a unique color for a better visual representation. The downtown area located in the middle of Syracuse is colored in black and is surrounded by the remaining seven city areas that were colored differently (Figure 4.2).

During a meeting with experts in the related field from Office of Innovation of Syracuse City, it was recommended to divide 8 major areas of Syracuse City further into neighborhoods in order to better represent population densities within the city boundaries as population density can vary within each area as well. The latest updated map version of the city neighborhood division indicates that the City of Syracuse consists of 32 neighborhoods that make up 8 major areas mentioned previously. In order to create a neighborhood map, a shapefile with neighborhood borders was applied on the street map that has been used for this research in previous sections, which contains information about every street segment such as street ID and road name. After the application of borders to the street shape file in ArcGIS, a new layer was created for every neighborhood with their corresponding roadway segments within their boundaries. Finally, an excel file was created where all of the road IDs were transferred and grouped based on the neighborhood in which they are located. All of the neighborhoods located in the City of Syracuse are shown on the map in Figure 4.3 where each neighborhood has a specific number assigned to it.

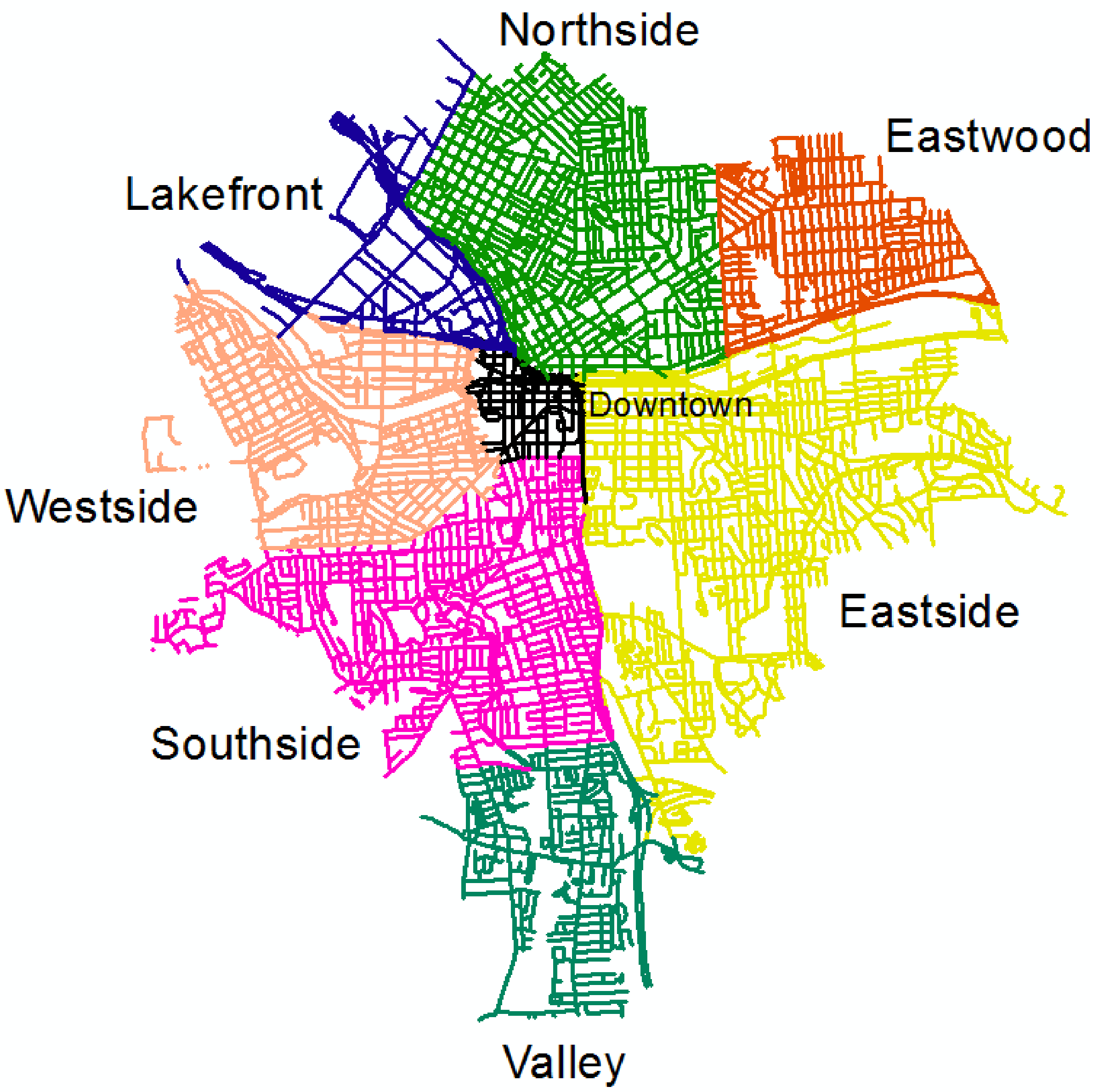


Figure 4.2: Major Areas within the City of Syracuse

1 – South Valley
2 – North Valley
3 – Brighton
4 – Elmwood
5 – Strathmore
6 – Winkworth
7 – Skunk City
8 – Tipp Hill
9 – Far Westside
10 – Park Ave.
11 – Near Westside
12 – Southwest
13 – Southside
14 – Downtown
15 – Lakefront
16 – Washington Sq.
17 – Northside
18 – Court-Woodlawn
19 – Sedgwick
20 – Franklin Sq.
21 – Prospect Hill
22 – Hawley-Green
23 – Lincoln Hill
24 – Eastwood
25 – Salt Springs
26 – Meadowbrook
27 – Near Eastside
28 – Westcott
29 – University
30 – South Campus
31 – Outer Comstock
32 – University Hill

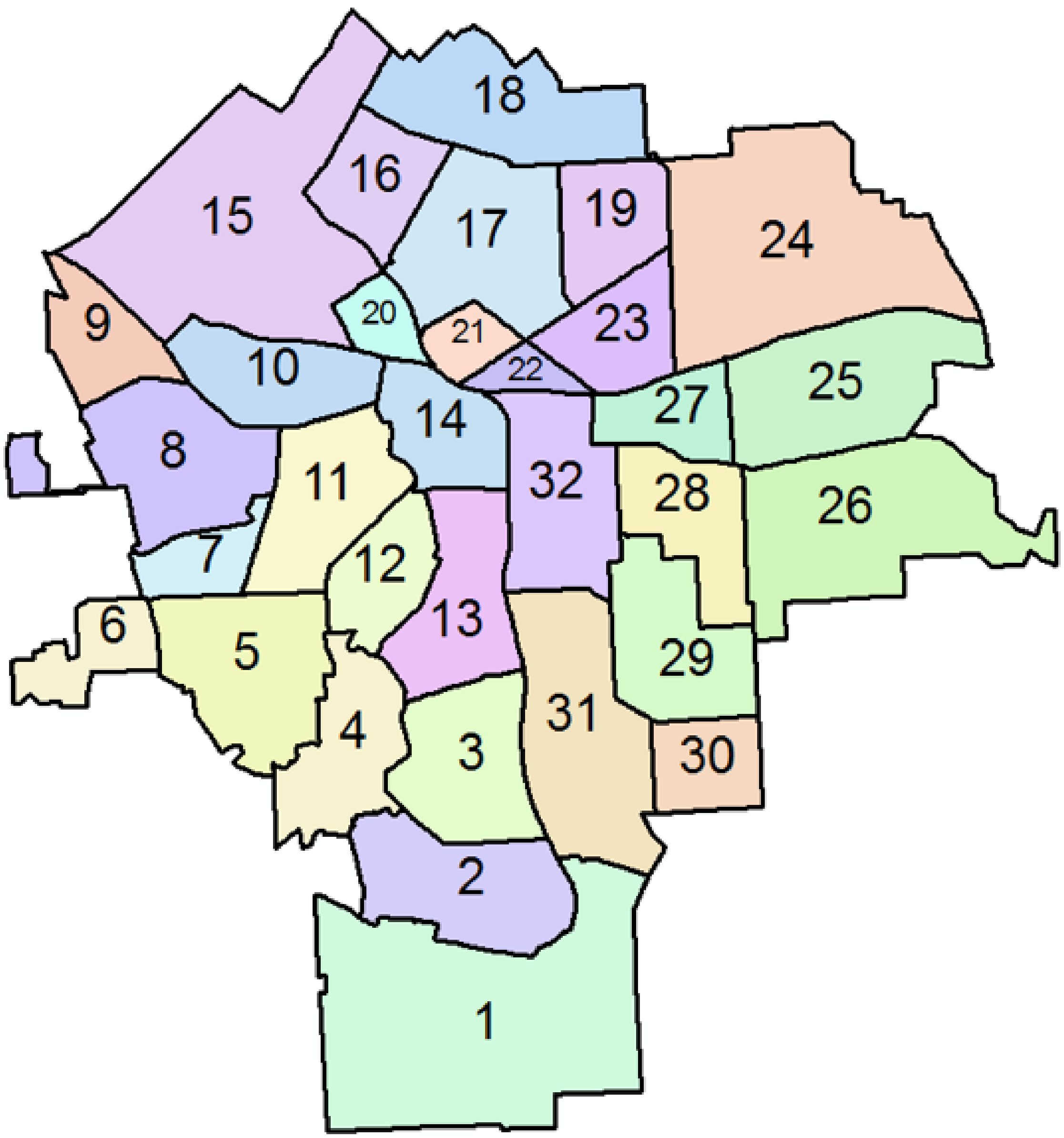


Figure 4.3: Neighborhood Borders of Syracuse City

Population density values were determined for every major area in Syracuse; therefore, the first assumption was that neighborhoods numbered from 16 to 23 would have the highest population densities since they are located in the area with the highest population density, which is 15.7 persons per acre (Table 4.2). In order to determine population density values of Syracuse neighborhoods, total number of people residing in a particular neighborhood was divided by the area of this neighborhood represented in acres. Populations of neighborhoods were found on the official website of Syracuse City (www.sygov.net). Neighborhood areas were measured in ArcGIS where the areas of 32 polygons representing neighborhoods in Figure 4.3 were found using the “measure” feature of the software. After population numbers and area sizes were determined, population densities were calculated for all neighborhoods in the City of Syracuse (Table 4.2). Neighborhoods with the highest population density values were determined as Washington Square, Hawley-Green and Prospect Hill numbered on the map as 16, 22 and 21, respectively. The assumption that neighborhoods with the highest population density values are located in major areas of Syracuse with the highest population densities from Table 4.1 was found to be correct. The neighborhood numbered 15 on the map with the lowest population density is located in the area that has the lowest population density out of 8 major areas. On the other hand, some neighborhoods such as University Hill numbered 32 on the map (Figure 4.3) are in top five neighborhoods with the highest population densities even though the major area in which it is located is 5^{th} out of 8 areas based on the population density (Table 4.1). As a result, the division of 8 major areas into 32 neighborhoods provides a better representation of how the population density is distributed within the City of Syracuse since it takes into account more diversified areas in terms of size and their locations.

Table 4.2: Population Density of Syracuse Neighborhoods

Neighborhood Name	Population	Area (acres)	Population Density (people/acre)	Map Number
South Valley	5,502	1,607	3.42	1
North Valley	5,024	553	9.08	2
Brighton	6,454	490	13.17	3
Elmwood	2,360	436	5.41	4
Strathmore	6,666	609	10.95	5
Winkworth	1,218	235	5.18	6
Skunk City	2,065	191	10.81	7
Tipp Hill	4,123	620	6.65	8
Far Westside	2,792	282	9.90	9
Park Avenue	2,822	395	7.14	10
Near Westside	7,030	484	14.52	11
Southwest	4,893	292	16.76	12
Southside	6,165	468	13.17	13
Downtown	2,440	326	7.48	14
Lakefront	40	1,354	0.03	15
Washington Square	11,876	311	38.19	16
Northside	4,752	621	7.65	17
Court-Woodlawn	6,454	617	10.46	18
Sedgwick	2,612	325	8.04	19
Franklin Square	362	133	2.72	20
Prospect Hill	2,229	124	17.98	21
Hawley-Green	1,944	94	20.68	22
Lincoln Hill	4,146	313	13.25	23
Eastwood	14,440	1,233	11.71	24
Salt Springs	4,658	701	6.64	25
Meadowbrook	4,565	920	4.96	26
Near Eastside	3,297	252	13.08	27
Westcott	5,836	393	14.85	28
University	2,669	495	5.39	29
South Campus	2,454	249	9.86	30
Outer Comstock	5,605	756	7.41	31
University Hill	8,015	523	15.33	32

4.2.3 Summary of Social Factors

After all of the neighborhoods were identified, ID numbers of roadway segments within each neighborhood were extracted from the ArcGIS file and placed in an Excel sheet so that they can be used in assigning social importance ratings during the prioritization process. In summary, the first category is used to evaluate the social importance of each roadway segment. It helps to describe how the roads affect the society by evaluating the amount of traffic each road can carry, the proximity of each roadway to socially important services and facilities, and the population densities of neighborhoods where the roadways are located. The hierarchy describing social importance of roadway segments and its sub-categories is represented in Figure 4.4**.**

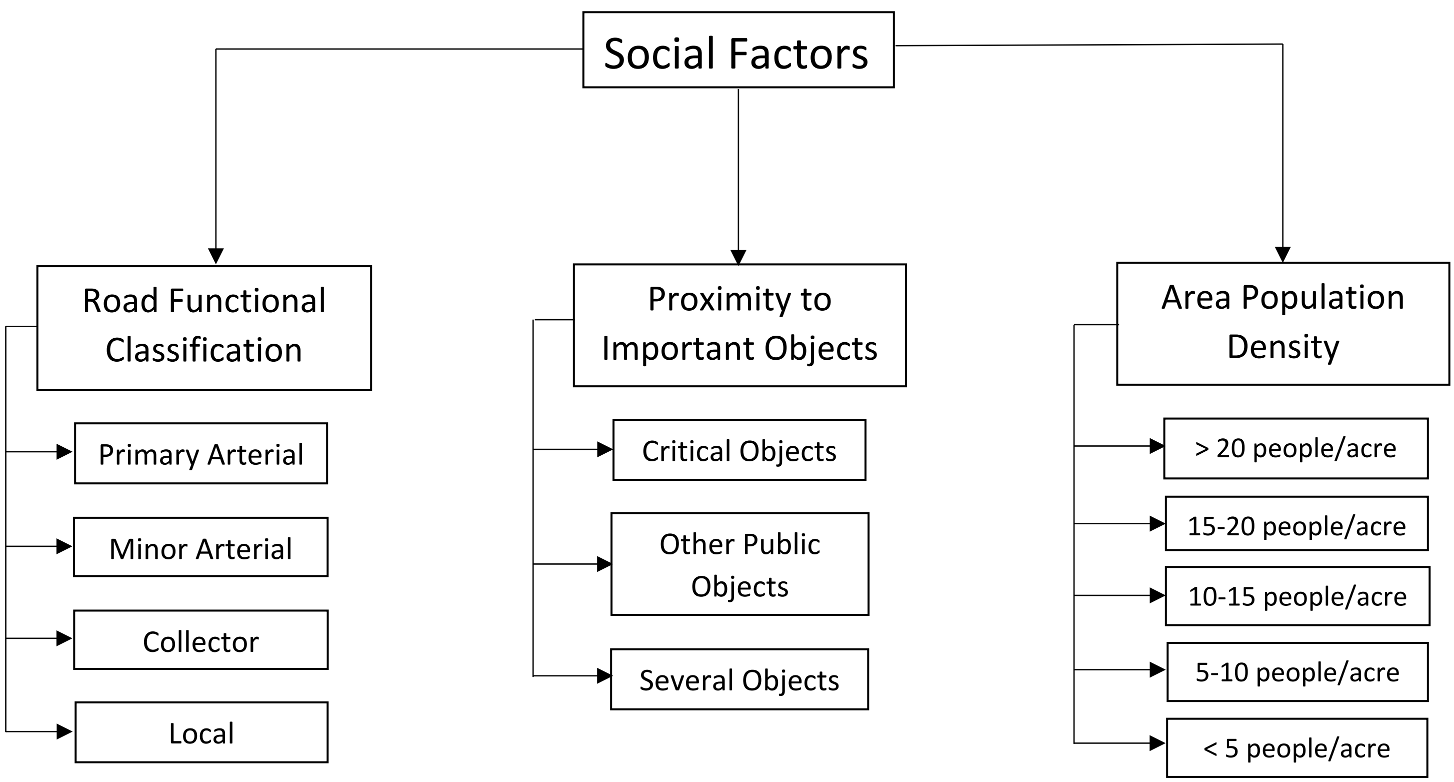


Figure 4.4: Hierarchy of the Social Importance Factors

4.3 Evaluation of Economic Factors

Roads in the City of Syracuse can be divided into three main types based on how they were constructed and what layers they consist of. The first type of the roadways are those with curbs installed and have at least three inches of asphalt over a concrete base. The second type is roads that have a full depth asphalt pavement of at least seven inches but have no concrete base and curbs. The last type of roads includes streets that have asphalt depth of three inches or less and do not have curbs or improved subbase. The last type of roadways generally includes residential streets and driveways.

As it was mentioned in the Methodology section, pavement types vary among different cities. Therefore, pavement types that are present in Syracuse may differ from pavements of other cities. Each roadway type will have a different cost of reconstruction since road segments have different lengths and layer compositions. The average cost data from the RS Means (2016) "Heavy Construction Cost Data" book were used in order to estimate the average cost of roadway construction. Some assumptions were made to compare construction costs of the roadways and generate the final amounts. It was assumed that only surface and base layers need to be demolished in cases when roads reach their serviceability limits. Additionally, it was assumed that all surface layers of the roadways in Syracuse have the surface course and the binder course. The minimum layer depths mentioned during the description of the three roadway types in Syracuse were used for cost estimating purposes. Finally, only excavation and paving costs were calculated to find final amounts and to compare the economic importance of the roadways.

All of the other assumptions are mentioned further in the description of cost estimating processes for each street type. The final cost amounts are calculated as the total costs including overhead and profit (Total Incl. O&P). Based on the definition from the Heavy Construction Cost Data, this cost represents the cost of materials plus 10% profit, the cost of labor plus labor burden and 10% profit, and the cost of equipment plus 10% profit (RS Means, 2016). It also should be noted that final reconstruction costs were adjusted using Syracuse Location Factor since the values provided in RS Means and following tables are based on national averages.

4.3.1 Road Type 1: Asphalt over a Concrete Base

The first type of roadway segments represents roads with curbs that have at least 3 inches of asphalt over a concrete base. The first step to estimate the road reconstruction cost if a roadway fails is to estimate the demolition cost of the failed road. For the first type of roads, 3 inches of asphalt and a concrete base need to be demolished assuming the subgrade remains in an adequate condition. Section 02 41 13.17 named “Demolish, Remove Pavement and Curb” of the RS Means manual was used to estimate the cost of one unit of work. These units can be represented as cubic yard (C.Y.), square yard (S.Y) or linear foot (L.F.) depending on the type of work performed. To estimate the demolition cost of the first type of roadways, the assumption was made that the concrete base of roadways is not reinforced with mesh or rods and is 7 inches in depth, which is a minimum depth that can be used according to the RS Means manual. After the demolition, 8 inches of asphalt base course is used instead of concrete base because it’s not prone to cracking and significantly less expensive than concrete. Then, asphalt paving consisting of binder and wearing course is placed on top of the base course. Section 32 11 23.23 “Base Course Drainage Layers” in the RS Means manual was used to estimate the cost of placing new asphalt base course. Section 32 12 16.13 named “Plant-Mix Asphalt Paving” of RS Means was used to estimate the cost of the new asphalt pavement. Based on the information obtained from city engineers, the top 3 inches of asphalt consist of 1 inch of wearing course and 2 inches of binder course. Finally, the cost of placing new curbs and gutters was calculated using Section 32 16 13.43 "Stone Curbs" assuming that granite curbs are needed. Even though granite curbs are significantly more expensive than concrete curbs, it was found that the City of Syracuse uses granite curbs as they tend to last longer in cold climates.

Table 4.3: Cost Estimation Steps for Reconstruction of Roads with Asphalt over a Concrete Base (RS Means, 2016)

RS Means #	Job Name	Depth	Unit of Work	Total Cost per Unit Work Incl. O&P
02 41 13.17 (5010)	Pavement removal, bituminous roads	3 inches	Square Yard (S.Y)	$5.85
02 41 13.17 (5400)	Concrete removal, plain	7 inches	Cubic Yard (C.Y)	$122
02 41 13.17 (6200)	Removal of curbs, granite	N/A	Linear Foot (L.F.)	$5.35
32 12 16.13 (0120)	Plant-mix asphalt paving; Binder course	2 inches	Square Yard (S.Y)	$9.55
32 12 16.13 (0300)	Plant-mix asphalt paving; Wearing course	1 inch	Square Yard (S.Y.)	$4.98
32 11 23.23 (0303)	Base course drainage layers; crushed 1-1/2" stone base; compacted	8 inches	Square Yard (S.Y)	$11.05
32 16 13.43 (1000)	Stone curbs; Granite, split face, straight, 5" x 16"	N/A	Linear Foot (L.F.)	$29.50

It was assumed that the removal of old and installation of new granite curbs is required for both sides of roadways when the total costs of reconstruction were calculated. The required steps for the cost estimating process of the first type of roads are summarized in Table 4.3. A sample calculation of determining the final reconstruction cost of one of the road segments with 3 inches of asphalt over a concrete base can be found in Appendix A.

4.3.2 Road Type 2: Full-Depth Asphalt

The second type of roadway segments that are present in Syracuse consists of roads with 7 inches of asphalt but without a concrete base or curbs. It is assumed that the asphalt depth consists of the wearing and binder courses that are laid on top of an improved subbase. First, the demolition cost was estimated using Section 02 41 13.17 "Demolish, Remove Pavement and Curb" of the RS Means manual. It was assumed that the roads have 3 inches of the wearing course and 4 inches of the binder course. Then, the cost of placing new bituminous pavement was estimated based on the Section 32 12 16.13 "Plant-Mix Asphalt Paving" from RS Means. Once again it was assumed that subbases of failed roads are in adequate condition and do not require reconstruction. The following table (Table 4.4) summarizes the steps required to estimate the reconstruction cost of the second type of roadways segments. It should be noted that the removal of the pavement was divided into two steps by removing a layer of 6 inches and 1 inch consecutively. This was done because the maximum asphalt removal depth provided in RS Means is 6 inches. It was possible to divide the pavement depth of 7 inches into two layers of other depth values (ex. 3 inches and 4 inches). However, removing two layers of 6 inches and 1 inch provides the highest unit price, which was utilized to avoid any potential underestimation issues.

The second type of road segments is typically less expensive to reconstruct than the first type of roadways due to their more simplistic design. In order to confirm that assumption, a roadway segment with a full-depth asphalt pavement was selected and compared with the segment from the sample calculation in Appendix A. It was found that the unit cost for reconstructing roadways with full-depth asphalt is approximately $50 per square yard of pavement. It is lower than the unit cost for reconstructing roads with 3 inches of asphalt over a concrete base where the unit costs is approximately $56 (not including installation and removal of granite curbs, which will significantly increase the final cost).

Table 4.4: Cost Estimation Steps for Reconstruction of Roads with Full-Depth Asphalt (RS Means, 2016)

RS Means #	Job Name	Depth	Unit of Work	Total Cost per Unit Work Incl. O&P
02 41 13.17 (5050)	Pavement removal, bituminous roads	6 inches	Square Yard (S.Y)	$9.55
02 41 13.17 (5010)	Pavement removal, bituminous roads	1 inch	Square Yard (S.Y)	$5.85
32 12 16.13 (0200)	Plant-mix asphalt paving; Binder course	4 inches	Square Yard (S.Y)	$18.50
32 12 16.13 (0460)	Plant-mix asphalt paving; Wearing course	3 inches	Square Yard (S.Y)	$15.45

4.3.3 Road Type 3: 3" of Asphalt

The third and the final type of roadway segments that are present in the City of Syracuse represents streets with 3 inches or less of asphalt that do not have curbs, concrete bases or improved subbases. Those streets are almost always residential roads and have the lowest cost of reconstruction among types of roadways that are present in Syracuse. It was assumed that these streets consist of 1 inch of wearing course on top and 2 inches of binder course underneath that connects the wearing course to the unimproved subbase. To estimate the demolition and construction costs, Section 02 41 13.17 and Section 32 12 16.13 of the RS Means book was used. It was assumed that all roadways of this type have 3 inches of asphalt for uniformity of calculations. All cost estimation steps required for evaluating roadways with 3 inches of asphalt with no curbs and improved subbases are summarized in Table 4.5.

Table 4.5: Cost Estimation Steps for Reconstruction of Roads with 3 Inches of Asphalt (RS Means, 2016)

RS Means #	Job Name	Depth	Unit of Work	Total Cost per Unit Work Incl. O&P
02 41 13.17 (5010)	Pavement removal, bituminous roads	3 inches	Square Yard (S.Y)	$5.85
32 12 16.13 (0120)	Plant-mix asphalt paving; Binder course	2 inches	Square Yard (S.Y)	$9.55
32 12 16.13 (0300)	Plant-mix asphalt paving; Wearing course	1 inch	Square Yard (S.Y)	$4.98

4.3.4 Summary of Economic Factors

In summary, rough cost estimations were performed to evaluate three types of roads that are present in the City of Syracuse. Cost estimates represent major expenses for demolition and re-paving of failed roads. The costs were estimated in order to compare the roadway segments within their pavement groups as well as between three types of roads that are present in Syracuse. It was assumed that the roadways' depths are uniform throughout the entire pavement cross-section even though the depth of roads tends to be larger in the middle and shallower toward the edges. This assumption was made to make the analysis and final results more uniform and more convenient to compare among road types. It was determined that 3052 out of 4860 evaluated road segments (62.8%) in Syracuse are roads that have at least 3 inches of asphalt over a concrete base. The remaining 1808 roadway segments consist of 163 road segments (3.4%) with full-depth asphalt and 1645 road segments (33.8%) with 3 inches of asphalt. The reconstruction cost values vary from $4,500 for small road segments made with 3 inches of asphalt to approximately $1,500,000 for extensive roads made with asphalt over a concrete base.

The reconstruction cost could not be determined for a few road segments as some of the roads do not have the necessary information provided in the database. As a result, a hierarchy describing the economic importance factors was developed to include all price ranges associated with the evaluated roads. A more detailed description of what information is missing is provided in the “Analysis with Assigned Weights” section. After the cost of reconstruction values were determined for all of the roadway segments, they were recorded in the excel spreadsheet to be used in determining the economic importance factors of the hierarchy. The following figure (Figure 4.5) represents a part of the hierarchy that describes economic importance of roadway segments in the prioritization tool developed in this research.

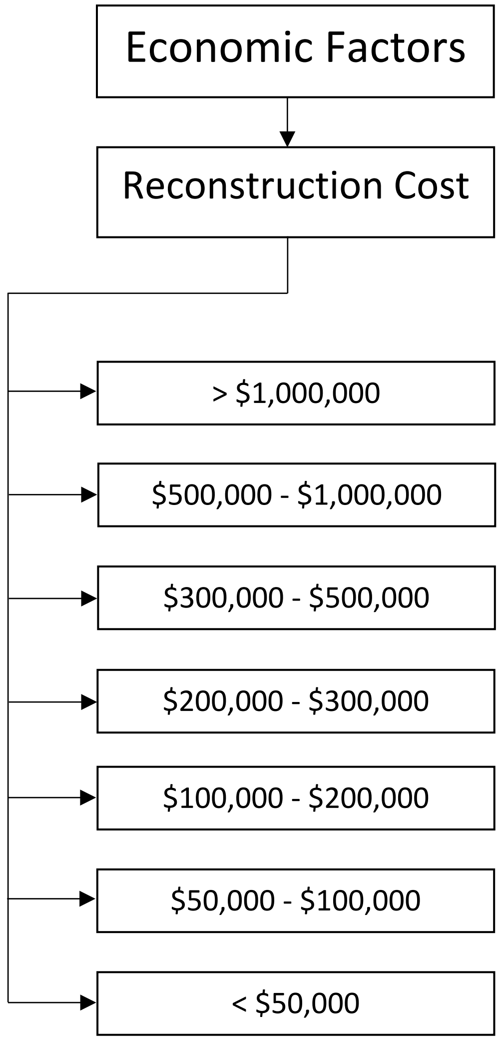


Figure 4.5: Hierarchy of the Economic Importance Factors

4.4 Evaluation of Environmental Factors

In order to evaluate environmental impacts, GWP and Energy Consumption values of roadway segments in Syracuse were determined by utilizing Athena’s Impact Estimator for Roadways. The program was developed to evaluate environmental impacts of final products, materials, transportation, construction and demolition processes. Even though the software was developed to be used in Canada, its parameters can be modified to be utilized in the US. Severity of environmental impacts depends primarily on the amount of resources required for a roadway reconstruction process. There are three types of pavements that are present within borders of the City of Syracuse: asphalt over a concrete base, full-depth asphalt and 3’’ of asphalt. All pavement types have different GWP and Energy Consumption values as they require different amounts of materials to be used. As a result, three types of pavements were designed and analyzed in Athena to generate results for environmental impacts. Global Warming Potential and Energy Consumption values were determined for 1 lane kilometer of roadways (Table 4.6), meaning that all of the recorded road length and width values have to be converted to appropriate units that represent the amount of lane kilometers per each roadway segment evaluated in this research. It can be argued that GWP and Energy Consumption values can be considered to be similar as they are interdependent. However, results in Table 4.6 show that differences in values for these parameters are not the same for three pavement types. Therefore, GWP and Energy Consumption values are influenced differently by evaluation criteria incorporated in the Athena’s software such as environmental impacts of material extraction or transportation.

Table 4.6: GWP and Energy Consumption Values for Reconstruction of Three Pavement Types

Pavement Type	GWP (kg CO2 Eq.) per lane km	Energy Consumption (MJ) per lane km
Asphalt over a Concrete Base	493,620	7,758,200
Full-Depth Asphalt	169,230	7,416,500
3'' Asphalt	77,655	3,403,000

It was assumed that road lanes have standard widths of 14 or 12 feet (depending on a road class) in order to do the conversion to lane kilometers. The width of each roadway segment was divided by the width of one lane (12 ft) to find an estimated number of lanes for each roadway segment. Then, the number of lanes was multiplied by the length values of roadways to determine the number of lane kilometers for each road segment. Finally, global warming potential values (in kg CO_2 eq) and energy consumption (in MJ) values were determined for each roadway segment based on the previous tables and were recorded in the excel file. The following figure (Figure 4.6) shows the environmental factors that were used to evaluate the environmental importance of the roadway segments within the City of Syracuse. The range values were assigned to the hierarchy based on the results after calculating environmental impacts for each road segment in the excel file. Sample calculations describing how the global warming potential and the amounts of energy consumption were found for all the street sections in the database are located in Appendix A.

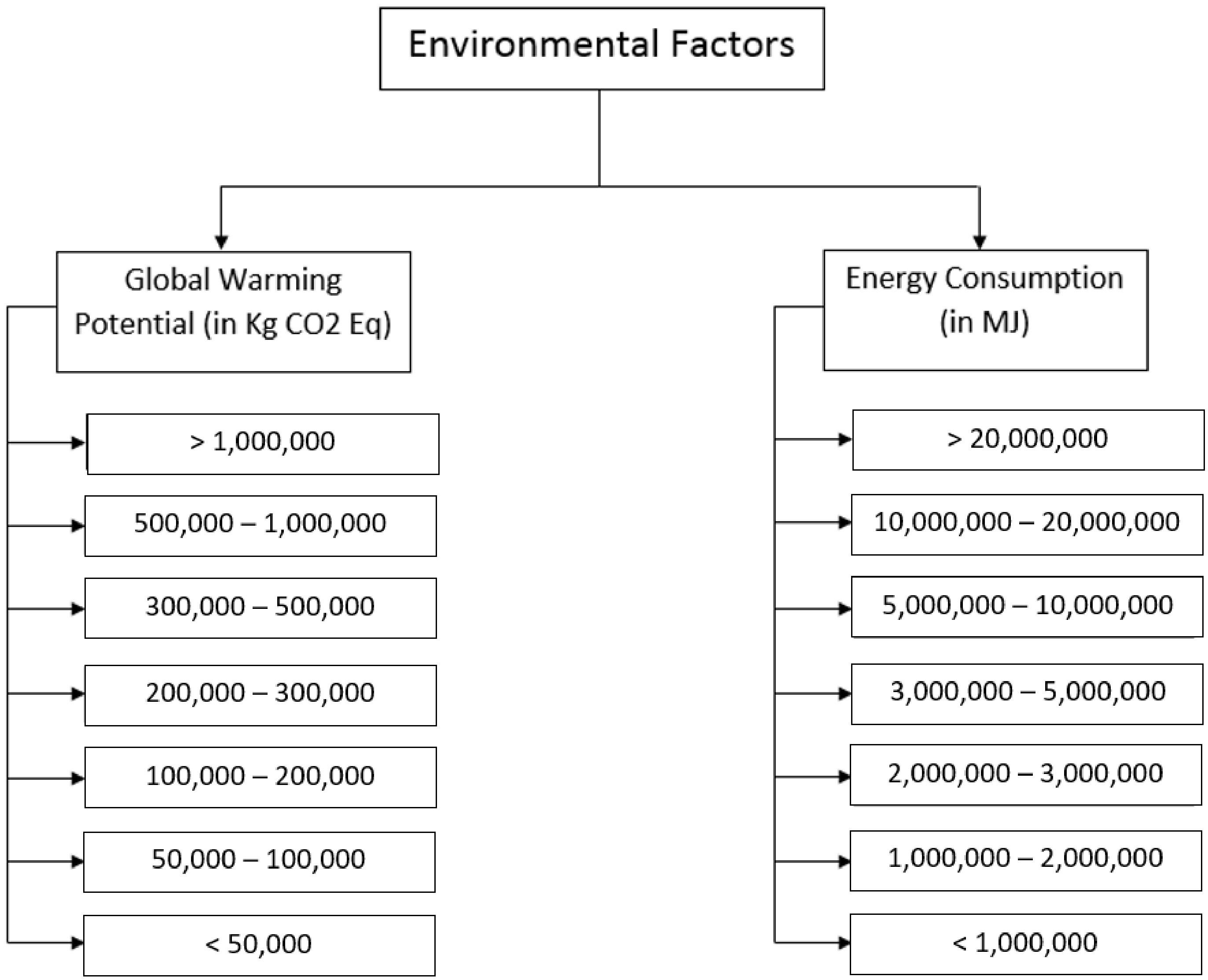


Figure 4.6: Hierarchy of the Environmental Importance Factors

4.5 Road Condition Ratings in Syracuse

In the database of roadway segments of the City of Syracuse, all of the roads within the city borders were monitored and evaluated based on a 2-3 year cycle. Each roadway segment was assigned three ratings at the time it was inspected: overall condition, cracking condition, and patching condition. The patching condition describes how a particular road segment is patched and the condition those patches. The patching rating was assigned on a 1-5 scale where 5 means that the road has no patches and 1 means that the road has more than 75% of its surface covered in patches that are in very poor condition. All of the patching ratings and their corresponding patch quality and frequency ranges that are used by the road inspectors in Syracuse are shown in Table 4.7**.**

Table 4.7: Road Rating Table for Patching Evaluation

Patching Rating	Patch Quality	Frequency (%)
5	No Patching	0
4	Good	10 - 25
3	Fair	25 - 50
2	Poor	50 - 75
1	Very Poor	> 75

The cracking rating that was assigned to each roadway segment in the database describes the frequency of developed cracks and how severe the cracking on a specific road is. The cracking rating was assigned on a 1-5 scale as well, where 5 represents no cracking and 1 represents a very severe cracking case with frequency higher than 50%. Cracking ratings that were used to describe the severity of cracking on the roadway segments analyzed in this research are summarized in Table 4.8. The ratings provided for the road segments describe severity and frequency of cracking, which can be used to evaluate street conditions; however, the method used for visual inspection of cracks does not differentiate crack types within their distress category making it unclear what type of cracking is predominant on the road segments. Although cracking is the most common type of distress that is visually evaluated by field engineers, this type of distress does not represent the entire variety of distresses that can develop on a roadway section.

Table 4.8: Road Rating Table for Cracking Evaluation

Cracking Rating	Severity	Frequency (%)
5	No Cracking	0
4	Slight	< 25
3	Moderate	< 50
2	Severe	25- 50
1	Very Severe	> 50

The overall condition of roadways represents the severity of all possible distress types that could develop on road segments. The overall condition requires a more careful assessment of the road segment since it has to incorporate all types of distresses that have developed on the street. Each road segment was assigned an overall rating value based on a rating scale from 1 to 10 where a rating of 10 represents a newly paved road with no distresses and a rating of 1 represents a road segment with a very severe distress with frequency of more than 75%. It is mentioned in the road rating rubric followed by the roadway inspectors that roadway segments with the overall condition rating below 5 are candidates for renovation or reconstruction. The following table (Table 4.9) demonstrates how rating values are divided in the overall condition rubric according to distress levels and distress frequency ranges.

Table 4.9: Road Rating Table for the Overall Condition Evaluation

Overall Rating	Distress Level	Frequency (%)
10	Newly Paved	0
9	No Distress	0
8	Very Slight	< 5
7	Slight	5 - 10
6	Moderate	10 – 25
5	Moderate	25 – 50
4	Severe to Moderate	25 – 50
3	Severe	50 – 75
2	Severe	> 75
1	Very Severe	> 75

4.6 Overview of the Hierarchy

The developed hierarchy of social, economic, and environmental factors was applied to the road segments in Syracuse. Sub-categories for all groups of factors were developed based on the data extracted from the database and applied to every roadway section. The full hierarchy describing all of the importance factors for the roadway segments in Syracuse is represented in Figure 4.7. After evaluating roadway segments in Syracuse using the developed hierarchy of roadway factors, it is possible to determine the significance level of every road section and combine it with street condition ratings to determine roads that require the most attention. The next chapter describes how importance scores and condition ratings can be combined based on two types of analyses.

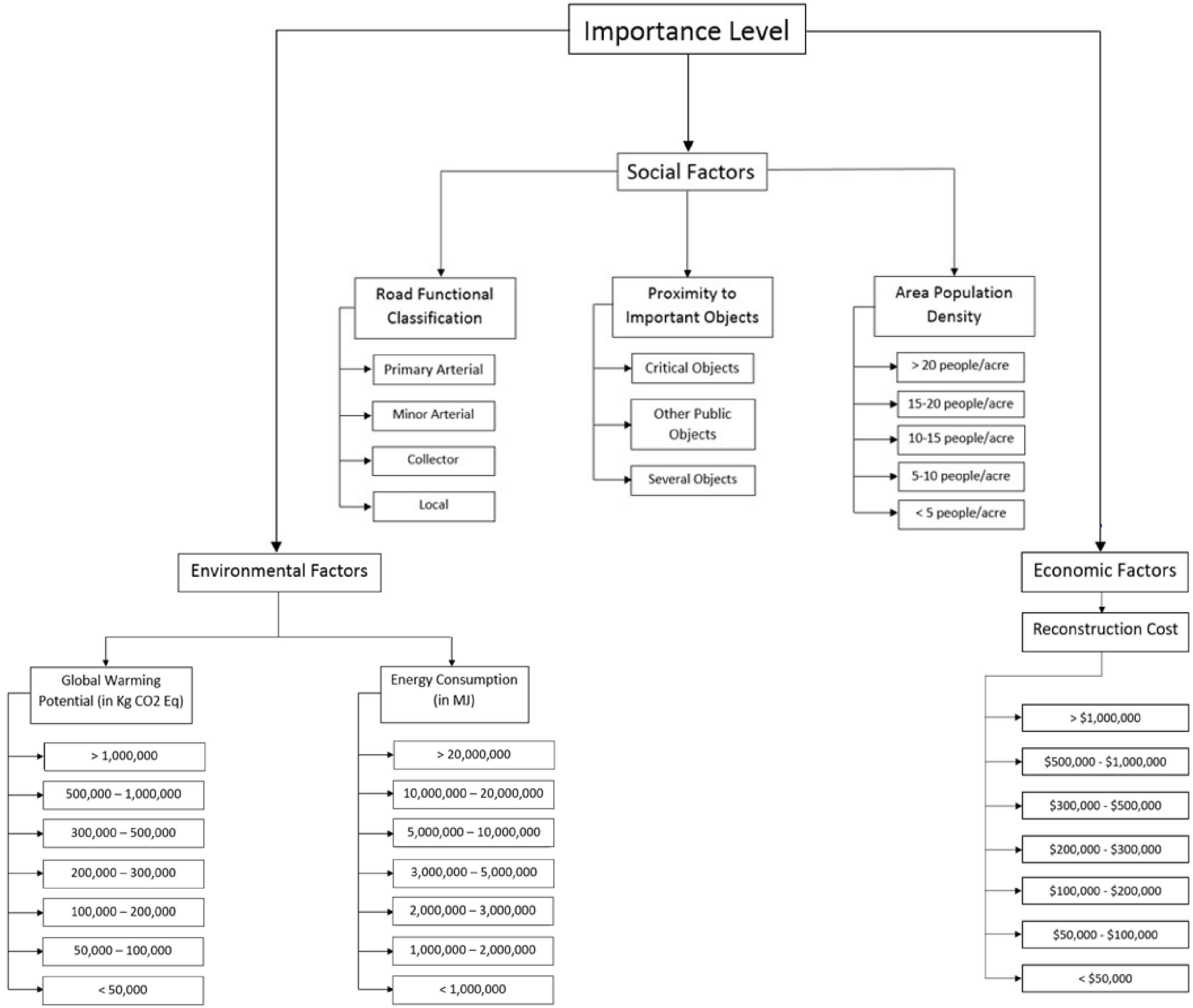


Figure 4.7: Hierarchy of the Importance Factors

Chapter 5

Analysis and Results

5.1 Analysis Overview

In order to analyze road segments listed in the database following the methodology described previously, it is necessary to assign weighting values to the factor groups (social, economic and environmental) in the hierarchy as well as to the sub-categories within those groups. The first type of the analysis (preliminary analysis) consists of prioritizing the roadways assuming that the weights of the factor groups in the hierarchy are the same and no priority is given to one group of factors over the others. The same logic is applied to the sub-categories within the groups where all sub-categories are assigned the same weighting values. The first analysis is called preliminary because it was conducted based on a feedback received at the first meeting with transportation experts employed by the City of Syracuse.

The second type of analysis (primary analysis) follows a different approach where the hierarchical categories and sub-categories are assigned different weight factors in order to differentiate the influence levels of the factors in the prioritization process. The weighting values were determined by conducting a survey among professionals in the related field who work for Office of Innovation of Syracuse City. After the second meeting held with the Office of Innovation at Syracuse City Hall, a short questionnaire was sent to all of the participants asking them to assign weights to each group of factors and their sub-categories based on their experience in the field. The questionnaire can be found in Appendix B. In the primary analysis, the assigned weight values served as a determining aspect for the outcome of the hierarchy analysis when the roadway segments were prioritized again. The analysis approach and the final step of the analysis with assigned weight factors was modified after the results of the first analysis were shown to the Innovation Team of the City of Syracuse. Finally, the results of two prioritization techniques are compared to determine their differences and to draw a conclusion.

5.2 Analysis with Equally Weighted Factors

The first part of the analysis with equal weights consists of the prioritization of road segments based on their social factors: road functional classification, proximity to important objects, and area population density in which the road segments are located. In this analysis, equal weight factors were assigned to each category and sub-category within the importance hierarchy. The final scores of the roads were obtained by multiplying final roadway ratings from the importance hierarchy and the corresponding values of the current conditions of the roads found in the database.

5.2.1 Ranking Based on the Social Factors

All of the 4898 roadway segments were assigned score numbers from 1 to 4 in order to rank them according to their road functional classification type where smaller numbers represent higher importance of a roadway. Principal arterial, minor arterial, collector and local types of roads were assigned numbers 1, 2, 3 and 4 to start the prioritization process, respectively. The results show that 282 road segments in the City of Syracuse are principal arterials, 889 roadways segments are minor arterials, 341 of them are collector roads and 3377 of segments are local roads. Only 9 roadway segments were not assigned a rank number due to lack of information.

After the first set of rank numbers was assigned to the road segments, ID numbers of the roads that were identified to be in a close proximity to important facilities or services were used to assign the second set of rank values. In the second ranking set, road segments that were identified to be in a close proximity of more than one important object were assigned a rank of 1. Segments that were identified to be in a close proximity of one critical object such as a fire station or a hospital were assigned a rank of 2. Rank 3 was assigned to roadways that are in a close proximity of one of other public objects such as universities and stadiums. Finally, roadway segments that are not within 1000 feet to any important object were assigned a rank of 4. The results showed that 228 roadways were assigned a rank of 1, 1243 road segments were assigned a rank of 2, 112 roads were assigned a rank of 3, and the rest 3315 roadway segments that are not in a close proximity of any important objects received a rank of 4.

The final part of ranking the roadway segments based on their social factors was to assign rankings to the streets depending on how populated the neighborhoods in which they are located are. All of the road segments with population density of more than 20 people per acre received a rank number of 1. Roads located in the neighborhoods with population density values of 15 to 20 people per acre, 10 to 15 people per acre, 5 to 10 people per acre and less than 5 people per acre were assigned rank values of 2, 3, 4 and 5, respectively. Some of the roads that served as a border between two neighborhood areas could be assigned to belong to any of two neighborhoods. Those roads were assigned to the area with a higher neighborhood density value if the neighborhood densities were within different density ranges. In cases when neighborhood densities fell into the same density category, the roads serving as borders between the neighborhoods were assigned to one of the neighborhoods randomly since it would not affect the final ranking results.

After three sets of ranks were assigned to every roadway segment with enough information provided in the database, an average value from three results was calculated for every roadway to determine the final rank values for the social importance category. Since the weighting factors for every social sub-category were the same, all social importance categories result in having the same level of influence on the final road ranks in the social importance category. The final results of the social importance evaluation showed that out of all evaluated road segments, 75 road segments stand out the most. None of the roads received a final rank of 1 based on their social importance factors since no road segment received a rank of 1 in all three social sub-categories. The first 75 road segments received the following rankings: 23 road segments received a rank of 1.33 while the following 52 segments received a rank of 1.67. The results of the social importance ranking show that many road segments received similar rank rating meaning that further prioritization based on economic and environmental parameters is necessary in order to better differentiate the roads. The top 100 roads from the social ranking analysis are presented in Table C-1 (Appendix C).

5.2.2 Ranking Based on the Economic Factors

Prioritization of the roadway segments according to their economic factors primarily depends on the pavement structure type of the streets since it determines to which sub-category of economic factors they belong to. Unlike in the social ranking process of the roads, each road segment can only be assigned one ranking value as only one of three sub-categories is applicable for all of the roadways. For instance, if a road segment is assigned a rank of 2 in the "Full-Depth Asphalt" sub-category, it cannot be assigned any other ranking since it does not belong to any of the two remaining sub-categories. In order to assign economic ranking values, reconstruction costs of roadways were calculated by dividing all of the roadways based on their pavement types. After reconstruction costs were calculated for all of the roadways, the road sections were grouped together to assign economic ratings. Ranking values that were assigned to the roadways based on their reconstruction costs are shown in Table 5.1.

As it was mentioned previously, approximately 63% of road sections are roads with asphalt over a concrete base making the first economic sub-category the largest one with higher distribution of cost ranges than the other sub-categories. All of the cost ranges that were used to prioritize the road segments are based on the distribution of reconstruction cost values of roadways within the entire database. After all of the ranking values were assigned for each roadway segment based on reconstruction cost, all of the road sections provided in the database were ordered according to their economic rank number from the lowest (rank value of 1) to the highest (rank value of 7). It was observed that only 5 roadway segments received the economic rating of 1 while the economic rating of 2 was assigned to 32 road sections. Top road sections that received the lowest economic ratings and the highest reconstruction costs are shown in Appendix C (Table C-2).

Table 5.1: Ranking System of Road Segments within Their Economic Category

Rank Assigned	Price Range ($)
1	> 1,000,000
2	500,000 – 1,000,000
3	300,000 – 500,000
4	200,000 – 300,000
5	100,000 – 200,000
6	50,000 - 100,000
7	< 50,000

5.2.3 Ranking Based on the Environmental Factors

The final part of the prioritization process is to rank the roadways according to their environmental impacts by assessing their global warming potential and energy consumption in case of a total reconstruction. All of the road segments were ordered according to their global warming potential where sections with higher global warming potential received lower rank numbers than those sections with lower global warming potential values. The same logic was applied during the ranking prioritization process of the roadways based on their energy consumption values that were calculated previously. Both “Global Warming Potential” and “Energy Consumption” sub-categories of the hierarchy have equal numbers of value ranges under them. The ranges of calculated values that were used for environmental sub-categories were determined based on the distribution of their corresponding environmental impact values and the quantity of road sections that have been evaluated. Rank values of 1 were assigned to the road segments that have global warming potential values of 1 million kilograms of CO_2 equivalent or more, and to the road segments with energy consumption values of 20 million megajoules or higher. Accordingly, street sections with global potential values of less than 50,000 kilograms of CO_2 Eq. and those sections that have energy consumption values of less than 1 million megajoules received the lowest rank number of 7. The distribution of rank values in environmental sub-categories is shown in Table 5.2.

Table 5.2: Rank Values in Environmental Sub-Categories

Environmental Category	***Range***	***Rank Value***
Global Warming Potential Values (Kg CO_2 Eq)	> 1M	1
	0.5M – 1M	2
	0.3M – 0.5M	3
	0.2M – 0.3M	4
	0.1M – 0.2M	5
	0.05M – 0.1M	6
	< 0.05M	7
Energy Consumption Values (MJ)	> 20M	1
	10M – 20M	2
	5M – 10M	3
	3M – 5M	4
	2M – 3M	5
	1M – 2M	6
	< 1M	7

All of the rank values between 1 and 7 were assigned to the appropriate range groups following an ascending order where lower rank numbers were assigned to the higher range groups. Since the weighting values of both environmental sub-categories are the same in this analysis, the overall environmental importance rank was calculated for every road section by calculating the average of both ranking results. Five road sections received a rank of 1 as their environmental importance rating, three sections received a rank of 1.5 and thirty-eight sections received a rank of 2. Top roadway segments with the highest environmental importance ratings were determined and are shown in Table C-3 (Appendix C).

5.2.4 Ranking Based on the Condition Ratings

After prioritizing all of the road segments by using the hierarchy of importance factors, the last step of the prioritization process is completed by assigning ranks to the sections based on their current condition ratings. The most recent condition ratings of the streets were assigned by field experts in 2015. The analysis of the database has shown that only one road from the entire database received a condition rating of 1 and 42 street segments received a current condition rating of 2. The ranking numbers were assigned to the road segments in accordance with their condition ratings where a road section with a condition rating of 1 (very severe) received a rank value of 1 while road sections with condition ratings of 10 (newly paved) received ranking values of 10. This prioritization process supports the idea that road segments that are in worse condition than other segments and require more immediate attention will receive low ranking numbers. The following table (Table 5.3) summarizes the information regarding current conditions of the roads in the City of Syracuse.

As it was mentioned previously, road sections with a current condition rating of 5 or lower are the strongest candidates for reconstruction or rehabilitation. The prioritization of streets based on their current condition ratings has shown that approximately 38% of all road segments in the database are candidates for renovation or reconstruction. It was observed that many road segments receive ratings of 5 and 6 because that is the location of the transition zone for the selection process; therefore, these ratings are most likely assigned with a higher level of consideration than the other condition ratings. A table containing top 100 road segments with the highest priority (Table C-4) based on their current condition ratings is located in Appendix C**.**

Table 5.3: Ranking Information Based on Current Condition Values

Rank Number Assigned	Current Condition/Distress Level	Number of Road Segments	Percentage of All Roads
1	1 / Very Severe	1	< 0.1%
2	2 / Severe	42	0.9%
3	3 / Severe	206	4.2%
4	4 / Severe to Moderate	510	10.4%
5	5 / Moderate	1077	22%
6	6 / Moderate	1449	29.6%
7	7 / Slight	823	16.8%
8	8 / Very Slight	524	10.7%
9	9 / No Distress	100	2.0%
10	10 / Newly Paved	114	2.3%
N/A	Not Specified	50	1.0%

5.2.5 Summary of the Analysis with Equal Weights

When all of the ranking results were obtained for the road segments based on their social, economic, and environmental importance factors in addition to the current condition ratings, final rating values of the analysis were calculated. Before the final ranking values were calculated, the overall importance ratings based on three groups from the hierarchy were determined by finding the average of those groups. Then, the final ranks of the analysis were assigned by multiplying the overall importance ratings and the current condition ratings of the road segments. This method is applied to calculate the final values because the weighting factors of the roadway importance and the current condition ratings were assigned to be the same for this type of analysis. The top 99 roadway segments with the lowest final ratings obtained from the analysis are represented in Table 5.4. Some road sections received the same final ratings due to similarities in their overall importance values and current condition values; therefore, only 99 (not 100) road segments are presented in Table 5.4 as the road sections ranked from 100 to 106 received the same final rating values and were not included in the table to keep the final quantity of roads within the first 100 road segments. In addition to the list of 99 critical roadway segments, a map with all of the roads in the City of Syracuse was analyzed to determine locations of all critical roadways. According to the risk maps, the critical road sections are more or less evenly distributed throughout the city meaning that no particular regions of the city received higher priorities than the others. It was determined that the number of critical roadway segments is lower in the Valley region of Syracuse (far south) due to the lower number of residents, important objects and primary roads.

Some of the road sections could not be evaluated to receive a final rating value because they are not described with sufficient information in the road database. For instance, some road segments from the database have sufficient information to evaluate their importance ratings using the hierarchy but lack information about their current condition ratings. On the other hand, some road sections have current condition rating assigned to them but do not have sufficient information to evaluate their environmental importance; therefore, the overall importance ratings of these street segments could not be found. From the final rating analysis of the road segments, it was determined that most of the roadways (76%) from the final table have a condition rating of 3 and below, which makes the condition rating to be a determining factor for calculations of the final ratings. Out of 99 roads with the lowest final ranking values, 37 road segments have a condition rating of 2, 37 street sections have a condition rating of 3, 10 sections have a condition rating of 4, 10 road segments with a condition rating of 5, and 4 road sections have a condition rating of 7. Only one roadway section has the most recent condition rating of 1 (very severe distress) and happens to be at the first place in the final ranking table (Table 5.4). The analysis with equal weight factors shows that the final results depend heavily on the current conditions of the roadways since overall importance ratings involve more factors and evaluating criteria.

Table 5.4: Top Road Segments with the Lowest Final Scores

Number	Street ID	Street Name	Street Type	Street Classification	Importance Rating	Condition Rating	Final
1	12577562	OSTROM	PL	Local	4.50	1	4.50
2	12578715	CROLY	ST	Local	3.50	2	7.00
3	12578695	SCOTTHOLM	TER	Local	3.61	2	7.22
4	12575236	EXCHANGE	ST	Local	3.83	2	7.67
5	12575226	PARK	ST	CO	4.00	2	8.00
6	12579997	PROSPECT	AVE	Local	4.06	2	8.11
7	12573444	NELSON	ST	Local	4.11	2	8.22
8	12577390	BURT	ST	MA	4.11	2	8.22
9	12579379	GENESEE	ST	PA	2.11	4	8.44
10	12577509	COMSTOCK	AVE	MA	1.72	5	8.61
11	12577557	COMSTOCK	AVE	MA	1.72	5	8.61
12	12575284	PARK	ST	CO	4.39	2	8.78
13	12578654	HARRINGTON	RD	Local	4.44	2	8.89
14	12578658	HARRINGTON	RD	Local	4.44	2	8.89
15	13013256	HARRINGTON	RD	Local	4.44	2	8.89
16	12575193	HIAWATHA	BLVD	MA	1.78	5	8.89
17	12575227	HIAWATHA	BLVD	MA	1.78	5	8.89
18	13018251	HIAWATHA	BLVD	MA	1.78	5	8.89
19	12578056	CROUSE	AVE	Local	4.50	2	9.00
20	12580097	DOUGLAS	ST	Local	4.50	2	9.00
21	12581006	GRANT	BLVD	MA	3.00	3	9.00
22	12581012	GRANT	BLVD	MA	3.00	3	9.00
23	13001229	GRANT	BLVD	MA	3.00	3	9.00
24	13006125	GRANT	BLVD	MA	3.00	3	9.00
25	13006126	GRANT	BLVD	MA	3.00	3	9.00
26	13006127	GRANT	BLVD	MA	3.00	3	9.00
27	13013186	CROUSE	AVE	Local	4.50	2	9.00
28	12577333	ALEXANDER	AVE	Local	4.56	2	9.11
29	12573140	CRESCENT	AVE	Local	4.61	2	9.22
30	12573182	CRESCENT	AVE	Local	4.61	2	9.22
31	12573183	CRESCENT	AVE	Local	4.61	2	9.22
32	12573673	ONEIDA	ST	Local	4.61	2	9.22
33	12578043	CROUSE	AVE	Local	4.61	2	9.22
34	12578051	CROUSE	AVE	Local	4.61	2	9.22
35	12578052	CROUSE	AVE	Local	4.61	2	9.22
36	12580110	CARBON	ST	Local	4.61	2	9.22
37	13013188	CROUSE	AVE	Local	4.61	2	9.22
38	13029619	ONEIDA	ST	Local	4.61	2	9.22
39	12572016	HILLVIEW	AVE	Local	4.67	2	9.33
40	12580075	HIGHLAND	ST	Local	4.83	2	9.67
41	12580494	WENDELL	TER	Local	4.83	2	9.67
42	12578124	HARRISON	ST	Local	4.94	2	9.89
43	12572989	HUBBELL	AVE	Local	5.00	2	10.00
44	12577365	CLINTON	ST	MA	3.39	3	10.17
45	12575233	HIAWATHA	BLVD	MA	3.44	3	10.33
46	12577778	MADISON	ST	Local	3.44	3	10.33

47	12575240	PARK	ST	Local	2.61	4	10.44
48	12579666	HEADSON	DR	Local	3.50	3	10.50
49	13010394	HEADSON	DR	Local	3.50	3	10.50
50	13010395	HEADSON	DR	Local	3.50	3	10.50
51	13010396	HEADSON	DR	Local	3.50	3	10.50
52	13010397	HEADSON	DR	Local	3.50	3	10.50
53	12575242	HIAWATHA	BLVD	MA	3.61	3	10.83
54	12575244	HIAWATHA	BLVD	MA	3.61	3	10.83
55	13002381	ERIE	BLVD	PA	2.17	5	10.83
56	12577708	LANDMARK	PL	Local	5.50	2	11.00
57	12580050	STRAND	PL	Local	5.50	2	11.00
58	12580453	RUGBY	RD	Local	5.50	2	11.00
59	12577750	IRVING	AVE	Local	2.78	4	11.11
60	12578242	BURNET	AVE	MA	2.78	4	11.11
61	13018654	IRVING	AVE	Local	2.78	4	11.11
62	12575293	PARK	ST	CO	3.72	3	11.17
63	12578772	FAYETTE	ST	CO	3.72	3	11.17
64	12574889	STATE FAIR	BLVD	Local	3.78	3	11.33
65	12574976	STATE FAIR	BLVD	Local	3.78	3	11.33
66	12574981	STATE FAIR	BLVD	Local	3.78	3	11.33
67	12575234	SALINA	ST	MA	3.78	3	11.33
68	12578049	HAWLEY	AVE	Local	3.83	3	11.50
69	12578253	CANAL	ST	Local	3.83	3	11.50
70	12578260	CANAL	ST	Local	3.83	3	11.50
71	12580624	BERKSHIRE	AVE	Local	3.83	3	11.50
72	12571899	PALMER	LN	Local	5.78	2	11.56
73	13001803	LODI	ST	MA	2.89	4	11.56
74	12574852	KANE	RD	Local	5.83	2	11.67
75	12580337	JASPER	ST	Local	5.83	2	11.67
76	12577660	STATE	ST	PA	2.33	5	11.67
77	12578849	ERIE	BLVD	PA	1.67	7	11.67
78	12579028	ERIE	BLVD	PA	1.67	7	11.67
79	12579670	ERIE	BLVD	PA	1.67	7	11.67
80	13002524	STATE	ST	PA	2.33	5	11.67
81	13002525	STATE	ST	PA	2.33	5	11.67
82	12575092	CLINTON	ST	Local	3.94	3	11.83
83	12575095	CLINTON	ST	Local	3.94	3	11.83
84	12580068	CARBON	ST	Local	3.94	3	11.83
85	12578532	JANET	DR	Local	5.94	2	11.89
86	12580574	ROSS	PARK	Local	3.00	4	12.00
87	13001865	CANAL	ST	Local	4.00	3	12.00
88	12573202	KIRK	AVE	Local	4.06	3	12.17
89	12575110	STATE	ST	MA	4.06	3	12.17
90	12575112	STATE	ST	MA	4.06	3	12.17
91	12578237	CANAL	ST	Local	4.06	3	12.17
92	12578323	TEALL	AVE	PA	3.06	4	12.22
93	12573507	ERIE	BLVD	PA	2.44	5	12.22
94	12577397	BURT	ST	MA	4.11	3	12.33
95	12578118	ADAMS	ST	MA	4.11	3	12.33
96	13020776	BURT	ST	MA	4.11	3	12.33
97	12574897	ERIE	BLVD	PA	1.78	7	12.44
98	12578254	LODI	ST	MA	3.11	4	12.44
99	12578263	LODI	ST	MA	3.11	4	12.44

5.3 Analysis with Assigned Weighting Factors

The second analysis was performed based on the weighting factors assigned to each category and sub-category in the hierarchy by participating transportation engineers. The analysis methodology was modified after a meeting with the Syracuse Office of Innovation. Ranks assigned within sub-categories were put on a scale from 1 to 100 in order to better represent the importance of the roadways sections and to provide a uniform scale for social, economic and environmental groups. Converting all rank values to scale values from 1 to 100 also help provides a more meaningful final score results represented on a scale where roads with a score of 100 have the most importance. In addition, using the scale will eliminate a problem with sub-categories that have more rank values than the others. For instance, the Global Warming Potential sub-category has seven different ranges of CO_2 emission meaning that roadways were assigned rank values from 1 to 7 in the first analysis. Roads that were assigned the rank rating of 1 are contributing at least 20 times more Kilograms of CO_2 Eq than roads with assigned rank value of 7. As a result, converting rank values to scale values from 1 to 100 improve the accuracy of assigned ratings and places different values on a uniform scale. All of the converted scale value that were assigned to roadway segments in the final analysis are shown in Table 5.5. For instance, the Energy Consumption sub-category has seven different ranges of values, which were converted to a 1 to 100 scale and yielded results that are represented at the bottom of the table**.** It can be observed that 1 to 100 scale values represent range values considerably better than numbering from 1 to 7 because they take into account by how much one value is greater than the other. Note that an average value was used within each range to generate the scale values.

Table 5.5: Scale Scores Assigned within the Hierarchy

Category	*Sub-Category*	*Description*	*Scale Scores*
Social Factors	**Functional Classification**	Principal Arterial	100
		Minor Arterial	75
		Collector	50
		Local	25
	Proximity to Important Objects	In proximity of several objects	100
		In proximity of a critical object	75
		In proximity of a public object	50
		In proximity of no objects	25
	Population Density	Density of > 20 people per acre	100
		Density of 15-20 people per acre	80
		Density of 10-15 people per acre	60
		Density of 5-10 people per acre	40
		Density of < 5 people per acre	20
Economic Factors	**Reconstruction Cost ($)**	> 1,000,000	100
		500,000 – 1,000,000	75
		300,000 – 500,000	40
		200,000 – 300,000	25
		100,000 – 200,000	15
		50,000 - 100,000	7.5
		< 50,000	5
Environmental Factors	**Global Warming Potential Values (Kg CO2 Eq)**	> 1M	100
		0.5M – 1M	75
		0.3M – 0.5M	40
		0.2M – 0.3M	25
		0.1M – 0.2M	15
		0.05M – 0.1M	7.5
		< 0.05M	5
	Energy Consumption Values (MJ)	> 20M	100
		10M – 20M	75
		5M – 10M	37.5
		3M – 5M	20
		2M – 3M	12.5
		1M – 2M	7.5
		< 1M	5

5.3.1 Assigned Weights within the Hierarchy

Several meetings were held with local engineers from the City of Syracuse before weights were determined for each category and sub-category of factors presented in the hierarchy. Weights for each group were determined based on experience of four local experts who work for the city and are familiar with roadway segments that are analyzed in the research. After every participating engineer assigned his or her weights to the groups, the results were compared to determine their consistency. The weights assigned to the categories and sub-categories of factors by the local engineers were determined to be consistent. This means that experts prioritized similar groups in the hierarchy over others, which makes the results reasonable and applicable to the second analysis. The weights assigned for the groups of factors in the hierarchy and their corresponding standard deviation values are in Table 5.6. The transportation experts were asked to assign weight factors to social, economic and environmental categories as well as their sub-categories so that the sum of weights would be equal to 1. For example, the sum of weights 0.48, 0.25 and 0.27 within the social category is equal to 1. In addition, the main categories of factors were assigned weights as well in order to differentiate among each other. Assigning weighting factors greatly improves the accuracy of the results in the second analysis as they will help to determine what groups of factors are considered to be more important than others by the experts in the local transportation department. All of the experts had similar opinions regarding the weights for all hierarchical factors making standard deviation values for weights to be small (Table 5.6). It is also important to notice that while road sections were assigned multiple scale values in the Social and Environmental categories, each road segment was assigned only one scale value in the economic category since a roadway can only have one type of pavement. It can be noted that no weights were assigned within the economic category of factors since only reconstruction costs were used to evaluate the economic importance of roadway segments.

Table 5.6: Weights and Standard Deviations Assigned to Every Group of the Hierarchy

Social Factors			*Economic Factors*	*Environmental Factors*	
Weight: 0.55 Std. Dev: 0.12			**Weight: 0.32** Std. Dev: 0.08	**Weight: 0.13** Std. Dev: 0.05	
Road Functional Classification	*Proximity to Important Objects*	*Area Population Density*	**N/A**	*Global Warming Potential*	*Energy Consumption*
Weight: 0.48 Std. Dev: 0.02	**Weight: 0.25** Std. Dev: 0.04	**Weight: 0.27** Std. Dev: 0.02		**Weight: 0.38** Std. Dev: 0.10	**Weight: 0.62** Std. Dev: 0.10

5.3.2 Combining Importance Scores and Current Condition Ratings

Another major difference in the second type of analysis is the final part where calculated importance scores for roadway sections are combined with current condition scores to determine the final ratings. In the first analysis, the final road ratings were found by assuming that importance values obtained from the hierarchy and the current condition values have equal weighting values. Also, the final ratings were obtained by multiplying importance and condition ratings. In the analysis with assigned weighting values, the final step has been modified in order to generate more meaningful results. Since all of the importance values were converted to a 1 to 100 scale, it was decided to use final importance scores from the hierarchy along with current condition ratings to determine roadway sections that require the most attention. Following this approach, roads with highest importance scores derived using the hierarchy of factors and lowest current condition ratings, which are represented by the red area on the graph in Figure 5.1**,** are considered to be the most critical. On the other hand, roads with the lowest importance scores and highest condition ratings, which are represented by the green area in Figure 5.1**,** are considered to be the least critical.

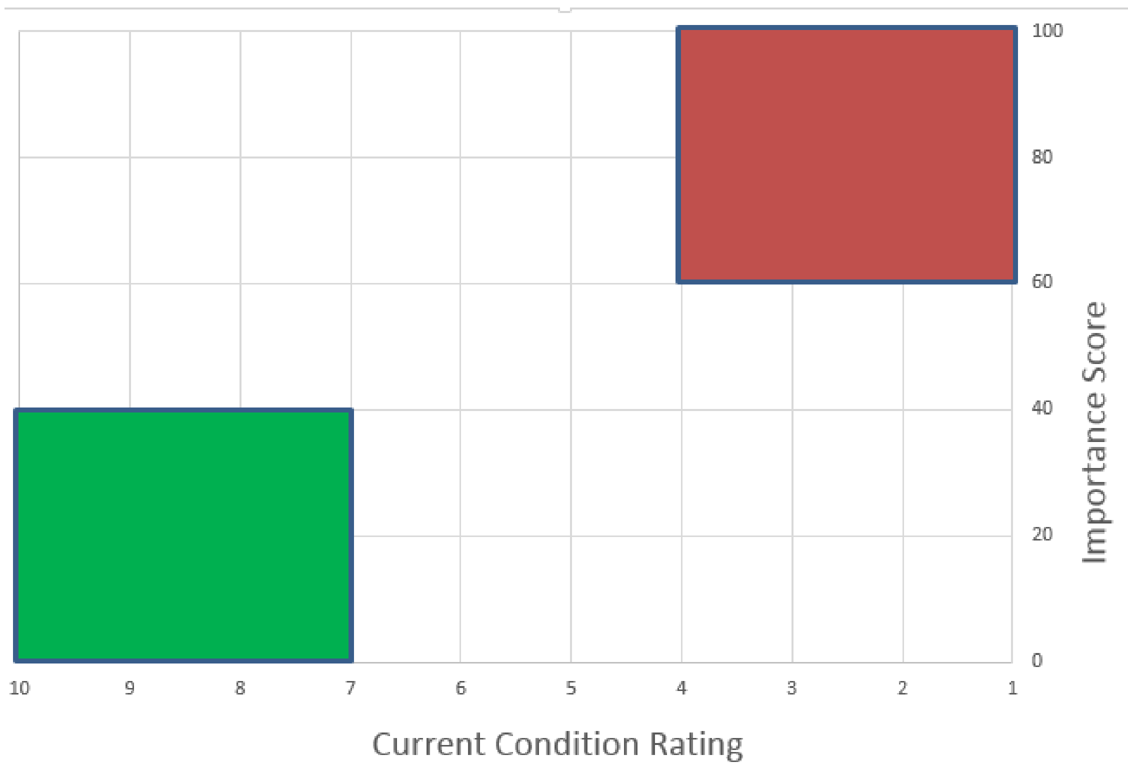


Figure 5.1: Road Evaluation Graph for the Second Analysis

In the second analysis where weights were assigned to categories and sub-categories within the hierarchy, it was determined that the roadway sections with the highest importance scores and the lowest current condition ratings require the most attention while roadways with the lowest importance scores and the highest current condition ratings require the least attention. These results effectively describe which roads need to be managed more closely. However, there is some uncertainty about the uncolored (white) area of the graph (Figure 5.1) that needs to be resolved by expert opinions. Some roadways may have high importance values meaning that they require more attention than the others in this category but also have high current condition ratings meaning that they are in adequate conditions and don't require much attention. On the other side, some roads may have low importance scores meaning they don't require much attention in this category but have low road condition ratings making them more important in the current condition category. Therefore, the major uncertainty is to determine what combination of factors in the middle of the graph (Figure 5.1) is more important based on a specific situation.

5.3.3 Assigned Importance Scores within the Hierarchy

Every road segment was assigned an importance score within every category and sub-category of the hierarchy so that it could be used with a current condition rating of the road to identify the most critical road sections within the City of Syracuse. After all of the roadway sections were assigned an importance score from 1 to 100 in every group of factors, the importance scores of every sub-category within social, economic and environmental category were combined based on the assigned weights (Table 5.6) in order to identify overall importance scores of each category. Similarly, final importance scores of the hierarchy were obtained using the assigned weight factors for social, economic, and environmental category that also can be found in Table 5.6 and are (0.55), (0.32) and (0.13), respectively. For instance, if a road segment received a score of 50 in the social category, a score of 100 in the economic category and a score of 100 in the environmental category, its final importance score would be equal to the sum of 27.5, 32 and 13, which is 72.5. The importance score values in each category of factors were obtained by multiplying their overall scores by weight factors assigned to them. It can be observed that the social group of factors received the highest weight since the transportation experts believe that this category addresses the most important aspects of how roadway sections impact people's lives. Roadway sections with the highest final importance scores are shown in Table C-5 of Appendix C**.** Out of 4898 roadway segments that were analyzed, 218 road sections did not have enough information to assign final importance scores. These roads have incomplete descriptions to calculate their social, economic, or environmental importance scores. Out of 218 road segments, only 7 road sections did not have sufficient information to assign scores in all three categories, 5 roads could not be assigned a social score, 18 roads could not be assigned an environmental score while 195 road sections were lacking information in economic and environmental groups. In addition to the roads lacking information to assign importance scores, there are 40 roadway segments that lack information regarding their condition ratings. As a result, there are 248 roadway sections that were not included in the analysis due to insufficient information.

5.3.4 Results of the Analysis with Assigned Weights

It was observed that out of 4898 roadway sections, only 42 roadways received final importance scores that are above 60 on the importance scale while the majority of road segments receiving overall importance scores of below 60. The lowest importance score assigned to 5 street sections is 15.11 while the highest score is 87.65, which was assigned to only one road section. After determining importance scores, they are combined with current condition ratings in order to identify the most critical road segments. Based on Figure 5.1, a critical zone colored in red includes roadways with importance scores of 60 and higher and current condition ratings of 4 and lower. The analysis returned too few roadways that have mentioned parameters. In order to increase the quantity of critical roadways, the critical zone was expanded to include roadways with importance scores of 50 and higher and condition ratings of 5 and below. The analysis with the modified critical zone returned 50 roadway sections that can be identified as the most critical. The critical roadways were identified based on two following factors: importance scores obtained from the hierarchy and current condition ratings assigned by field inspectors.

Although the road segments within the red zone are considered to be critical, it was decided to use normalized distances from the point on the graph assigned for each roadway to the point considered the most critical. The most critical location on the graph is the point where the road importance value is 100 and the road condition rating is 1 (X: 1, Y: 100). The condition rating of roadways is located on the x-axis of the graph (Figure 5.1) where the highest value is 10 (X max) and the lowest value is 1 (X min). The importance score is located on the y-axis with the highest and the lowest value of 100 (Y max) and 15.11 (Y min), respectively. The lowest value on the y-axis was determined to be 15.11 after analyzing the results of the final analysis. The set of equations utilized to find distances to the most critical point on the graph is presented in Figure 5.2. It should be noted that the equations for normalized x and y distance are not the same due to the inconsistent scales used (i.e. 1 worst - 10 best vs. 100 most important - 15.11 least important). While 100 is the most critical value on the importance score axis (y-axis), the most critical value on the condition rating axis (x-axis) is 1, which is directly opposite.

$$\textbf{Distance} = \sqrt{(Xn)^2 + (Yn)^2}$$

$$\textbf{Xn} = \frac{X - Xmin}{Xmax - Xmin}$$

$$\textbf{Yn} = \frac{Ymax - Y}{Ymax - Ymin}$$

$$\textbf{Xmax} = 10;\ \textbf{Xmin} = 1$$

$$\textbf{Ymax} = 100;\ \textbf{Ymin} = 15.11$$

Figure 5.2: Distance to the Critical Point Equation

When critical distances of all road segments were calculated, the road segments within the critical zone were ranked according to the critical distance value (Table 5.7). A lower critical distance of a particular road means that the road is closer to the critical point (X: 1, Y: 100) on the graph. Utilizing the critical distance approach helps to order roadways within the critical zone and identify roadways that are closer to the most critical point identified previously.

Table 5.7: Prioritized Road Segments within the Critical Zone

Number	Street ID	Street Name	Street Type	Overall Importance	Condition Rating	Xn	Yn	Critical Distance
1	12579379	GENESEE	ST	72.78	4	0.333	0.321	**0.463**
2	12577509	COMSTOCK	AVE	79.04	5	0.444	0.247	**0.508**
3	12577557	COMSTOCK	AVE	79.04	5	0.444	0.247	**0.508**
4	12575193	HIAWATHA	BLVD	72.53	5	0.444	0.324	**0.550**
5	13018251	HIAWATHA	BLVD	72.53	5	0.444	0.324	**0.550**
6	13020311	BEAR	ST	72.53	5	0.444	0.324	**0.550**
7	12581012	GRANT	BLVD	56.13	3	0.222	0.517	**0.563**
8	13001229	GRANT	BLVD	53.62	3	0.222	0.546	**0.590**
9	13006125	GRANT	BLVD	53.62	3	0.222	0.546	**0.590**
10	13006126	GRANT	BLVD	53.62	3	0.222	0.546	**0.590**
11	13006127	GRANT	BLVD	53.62	3	0.222	0.546	**0.590**
12	12581006	GRANT	BLVD	52.22	3	0.222	0.563	**0.605**
13	12578348	TEALL	AVE	56.70	4	0.333	0.510	**0.609**
14	12575064	BEAR	ST	62.68	5	0.444	0.440	**0.625**
15	12575227	HIAWATHA	BLVD	62.68	5	0.444	0.440	**0.625**
16	12577672	STATE	ST	54.73	4	0.333	0.533	**0.629**
17	12573507	ERIE	BLVD	61.05	5	0.444	0.459	**0.639**
18	12577357	STATE	ST	59.90	5	0.444	0.472	**0.649**
19	13002509	STATE	ST	59.90	5	0.444	0.472	**0.649**
20	13002381	ERIE	BLVD	59.56	5	0.444	0.476	**0.651**
21	12577894	ERIE	BLVD	52.22	4	0.333	0.563	**0.654**
22	13001803	LODI	ST	51.33	4	0.333	0.573	**0.663**
23	13002524	STATE	ST	58.08	5	0.444	0.494	**0.664**
24	13002525	STATE	ST	58.08	5	0.444	0.494	**0.664**
25	12573466	ERIE	BLVD	56.93	5	0.444	0.507	**0.674**
26	12578910	GENESEE	ST	56.93	5	0.444	0.507	**0.674**
27	12578912	GENESEE	ST	56.93	5	0.444	0.507	**0.674**
28	12578917	GENESEE	ST	56.93	5	0.444	0.507	**0.674**
29	12578924	GENESEE	ST	56.93	5	0.444	0.507	**0.674**
30	12577881	ERIE	BLVD	56.70	5	0.444	0.510	**0.677**
31	13020698	ONONDAGA	ST	56.13	5	0.444	0.517	**0.682**
32	12577660	STATE	ST	55.11	5	0.444	0.529	**0.691**
33	12577671	STATE	ST	54.73	5	0.444	0.533	**0.694**
34	12578313	TEALL	AVE	54.73	5	0.444	0.533	**0.694**
35	12578314	TEALL	AVE	54.73	5	0.444	0.533	**0.694**
36	13001800	ERIE	BLVD	53.73	5	0.444	0.545	**0.703**
37	12577706	STATE	ST	53.32	5	0.444	0.550	**0.707**
38	12578908	GENESEE	ST	53.32	5	0.444	0.550	**0.707**

39	12576554	SALINA	ST	53.16	5	0.444	0.552	**0.709**
40	13018654	IRVING	AVE	52.82	5	0.444	0.556	**0.712**
41	12577702	STATE	ST	51.76	5	0.444	0.568	**0.721**
42	12579371	GENESEE	ST	51.76	5	0.444	0.568	**0.721**
43	12579557	GENESEE	ST	51.76	5	0.444	0.568	**0.721**
44	12579559	GENESEE	ST	51.76	5	0.444	0.568	**0.721**
45	13013344	BURNET	AVE	51.33	5	0.444	0.573	**0.725**
46	13028362	LEMOYNE	AVE	51.33	5	0.444	0.573	**0.725**
47	12571879	GEDDES	ST	51.23	5	0.444	0.575	**0.726**
48	12578703	GENESEE	ST	50.17	5	0.444	0.587	**0.736**
49	12580512	TEALL	AVE	50.06	5	0.444	0.588	**0.737**
50	13002516	STATE	ST	50.06	5	0.444	0.588	**0.737**

5.3.5 Summary of the Analysis with Assigned Weights

The analysis with assigned weights has generated results where groups of roadway factors with higher influence on the decision-making process were emphasized and helped generate more accurate results. The analysis with assigned weights generated results where critical roadway segments tend to belong to one continuous street. This means that if one segment of a specific road was identified to be critical, there was a high chance that several more segments of this roadway would be critical as well. As a result, there are 20 road sections from the top 50 list (Table 5.7) that belong to only two roadways. Similarly, most of the other roads represented in the top 50 list of critical roadways have more than one segment in that list. Locations of the top 50 roadways were identified in order to evaluate the results even further. Due to the modified weighting factors assigned to the groups within the hierarchy, the top critical roadways are influenced more by the groups of factors that were assigned higher weight values than the others. For instance, most of the roadways in the top 50 list have higher road classification ranks where 30 of them are primary arterial, 19 streets are minor arterials and only 1 road is local. These results were obtained because the road classification sub-category was assigned a higher importance weight than other social groups, and the social category itself was assigned the highest weight factor. As a result, many roadways with high functional classifications such as primary and minor arterials received higher importance scores and were identified as critical based on the analysis with assigned weights.

Chapter 6

Discussion and Conclusion

6.1 Comparison of Analysis Methods

Two approaches used in two analysis methods generated different final results although they had some similarities. In the first analysis, critical roadways were determined by combining final importance scores and condition ratings in order to generate final prioritization scores. However, in the second analysis, roadway segments are placed into the defined critical zone by evaluating them based on both the importance scores and current condition scores without combining them. This approach helped to incorporate the new method of analyzing roadways based on factors from the hierarchy developed for this research with the road condition values that are currently used by local transportation authorities as their major prioritization tool. It was possible to state which roadways are more critical than others within the critical zone by calculating normalized x and y values to identify their critical distances.

Even though the analyses in this research had several major differences and followed different approaches, they have shown some similarities in the results that they generated. Since the second analysis identified 50 roadways to be within the critical zone, these roadways were compared with the top 50 roadways generated by the first analysis to identify any similarities. The following table (Table 6.1) shows the roadway segments that were identified as critical by both analysis methods.

There are 12 roadway segments that were identified as critical by both analysis methods, meaning that they need to be managed closely since they are crucial for the residents of Syracuse and will have severe negative impacts if they fail. In this research, roadway failure (serviceability limit) was identified as a road condition when a particular roadway is not safe to drive on and the only option to improve it is the total reconstruction. It can be observed that most of the roadways in Table 6.1 are represented by several road segments. This is meaningful for road maintenance and management purposes because when one segment needs rehabilitation, it is reasonable to rehabilitate the entire chain of roadway sections belonging to one street. Although the analyses had some major differences, it is possible to conclude that results generated have some consistencies as they have approximately 25% of similar street sections when top 50 roadways segments from both analyses are compared.

Table 6.1: Critical Roadway Segments Presented in Both Analyses

Number	Street ID	Street Name	Street Type
1	12579379	GENESEE	ST
2	12577509	COMSTOCK	AVE
3	12577557	COMSTOCK	AVE
4	12575193	HIAWATHA	BLVD
5	13018251	HIAWATHA	BLVD
6	12581012	GRANT	BLVD
7	13001229	GRANT	BLVD
8	13006125	GRANT	BLVD
9	13006126	GRANT	BLVD
10	13006127	GRANT	BLVD
11	12581006	GRANT	BLVD
12	12575227	HIAWATHA	BLVD

6.2 Limitations

There are several factors that may have affected the accuracy of the results. One of the possible factors that could contribute to the error in the final results is the accuracy of the assigned current condition ratings to the roadway segments. It was observed from the database that many of the overall ratings that are assigned to the roadway segments follow a quick transition from 9 to 6 and have a steadier transition from 6 to 5 since ratings of 5 and below indicate that a roadway segment becomes a candidate for renovation according to the general rule followed by Syracuse City engineers. Therefore, it is probable that a field inspector takes extra time and evaluates a specific road more carefully to make a judgement if the roadway segment is a true candidate for renovation or reconstruction while paying less attention when assigning higher condition ratings.

The second factor that could have impacted the accuracy of the result is the consistency of assigned condition ratings throughout the period of 15 years. Many of the research data are based on the personal judgement of field engineers who performed the field inspection of roads in the City of Syracuse and have been assigning the condition ratings throughout the last 15 years. Nevertheless, it is more likely that many roads were evaluated by different field engineers who could have different opinions about severity of distresses on roadways. Although field experts use a standardized approach to rate conditions of roadways, it is possible that the standardized method is interpreted with some dissimilarities among inspectors.

Another possible error factor could be the amount of detail incorporated in the assigned condition scores. The rating rubrics that are followed to evaluate road segments do not address all of the distress types because only the cracking and patching conditions are recorded. In addition, the records of the provided distress categories do not have a differentiation among distresses within the category but rather generalize them under one group.

Finally, there were some road sections that could not be evaluated due to lack of available information in the database. There is still a chance that some of them could have been identified as critical if sufficient data were provided.

6.3 Conclusions

Local transportation authorities of cities like Syracuse encounter many challenges in determining what roadway segments need to be managed closely. The major issues include limited budgets and absence of a unified guideline that can be followed by local experts to distribute resources. This research was conducted to improve the efficiency of distributing resources for transportation needs and to guide decision-makers through the road prioritization process. The main purpose of two prioritization techniques developed in this research is to identify roadway sections for which resources have to be allocated in order to keep them in adequate condition. As time passes, the roadways identified as the most critical will deteriorate and will have negative impacts on the residents and economy of Syracuse in case of reaching their serviceability limit. The list of critical roadways can help engineers to identify what roadway sections need to be managed closely to avoid their failure as they have high importance based on social, economic and environmental consequences analyzed in this research. Even though some roadways can have higher importance scores than those identified as critical, their pavement conditions are sufficiently high and do not require immediate attention. For instance, if a road section has a condition rating of 6 and an importance score of 70, this road section will not be considered as critical based on the parameters used for this research because its condition is adequate (not 5 or below).

The prioritization method used in this study focuses on the current situation of road sections and has to be modified every year in order to generate accurate results. Importance scores assigned to every road segment may change over years if factors like population density do not stay the same. Condition ratings of roadways will decrease at different rates, which will impact the prioritization results in the years to come. As a result, it can be recommended for future research studies to evaluate and expand existing road prioritization models in order to address the dynamics of previously mentioned criteria.

The roadway factors that affect the importance scores of local roadways can be considered as static because there is a small chance that any of them will change soon. For example, it is highly unlikely that factors such as roadway classification or proximity to important objects from the social category will be different for any of the road sections in one year. Even though the importance factors of the hierarchy stay more or less the same, the most recent condition ratings of the roadways can change quickly during one year after the analysis. Therefore, it should be noted that a certain number of roadway segments may move to the critical zone as they become more deteriorated. An ideal approach to manage roadways would be to run a prioritization analysis annually to observe how the number of critical road sections change with time. Finally, it is also important to keep in mind that the chance of the importance scores to change may increase with time.

The prioritization tool can be used by transportation experts not only to generate results based on a combination of factors but also to analyze roadways based on a single parameter like the cost of total reconstruction if they believe that this factor is more important for a particular situation. In addition, the model can be used to evaluate past decisions and compare them with results of this analysis in order to determine differences in main contributing factors during decision-making processes. The ultimate decision about resource allocation and priority distribution will be made based on personal opinions and experience of decision-makers. However, by using the prioritization model as a guiding tool, it can become easier to make accurate systematic decisions regarding management of roadways.

Appendix A:

Sample Calculation of the Reconstruction Cost:

Road Type: 3 inches of asphalt over a concrete base

Road Segment ID: 12571879

Road Name: GEDDES ST

Length: 1530 ft; **Width:** 36 ft

Depth of Concrete Base: 7 in = 0.583 ft

Total Area: 1530 ft x 36 ft = 55,080 ft^2 = 6,120 yd^2

Cost per Square Yard (S.Y.) of Work:

- Pavement removal, bituminous roads = $5.85
- Plant-mix asphalt paving; Binder course = $9.55
- Plant-mix asphalt paving; Wearing course = $4.98
- Crushed stone base; compacted to 8" deep = $11.05
    - **Total** = $5.85 + $9.55 + $4.98 + $11.05 = $31.43

Cost per Linear Foot (L.F.) of Work:

- Removal of curbs, granite = $5.35 x 2 (both road sides) = $10.70
- Installation of new curbs, granite = $29.50 x 2 (both road sides) = $59
    - **Total** = $10.70 + $59 = $69.70

Cost per Cubic Yard (C.Y.) of Work:

- Concrete removal, plain = $122

Volume of Concrete Removed in C.Y.

- 0.583 ft (depth of concrete base) x 55,080 ft^2(total area) = 32,112 ft^3 = 1190 yd^3

Total Cost of Reconstruction:

- ($31.43 per yd^2 x 6,120 yd^2) + ($69.70 per ft x 1530 ft) + ($122 per yd^3 x 1190 yd^3) = **$444,173**
- $587,687 x (Syracuse Location Factor) = $444,173 x 0.983 = **$442,360**

<u>Sample Calculation of Global Warming Potential (GWP)</u>

Road Segment ID: 12571879

Road Name: GEDDES ST

Road Functional Classification: Minor Arterial

Pavement Type: Asphalt over a Concrete Base

Length: 1530 ft

Length in Kilometers: 1530 ft x (1 km / 3280.84 ft) = 0.466 km

Width: 36 ft

Average Lane Width: 14 ft

Number of Lanes: 36 ft / 14 ft = 2.57

GWP of a Pavement with Asphalt over a Concrete Base:

493,620 (kg CO_2 eq. per 1 lane km)

Number of Lane Km:

(Number of Lanes) x (Length in Kilometers) = 2.57 x 0.466 = **1.198 lane km**

Global Warming Potential Value:

- 493,620 (kg CO_2 per 1 lane km) x 1.198 lane km = **591,357 kg CO_2 eq.**

Sample Calculation of Energy Consumption

Road Segment ID: 12571879

Road Name: GEDDES ST

Road Functional Classification: Minor Arterial

Pavement Type: Asphalt over a Concrete Base

Length: 1530 ft

Length in Kilometers: 1530 ft x (1 km / 3280.84 ft) = 0.466 km

Width: 36 ft

Average Lane Width: 14 ft

Number of Lanes: 36 ft / 14 ft = 2.57

Energy Consumption of a Pavement with Asphalt over a Concrete Base:

7,758,200 (MJ per 1 lane km)

Number of Lane Km:

(Number of Lanes) x (Length in Kilometers) = 2.57 x 0.466 = **1.198 lane km**

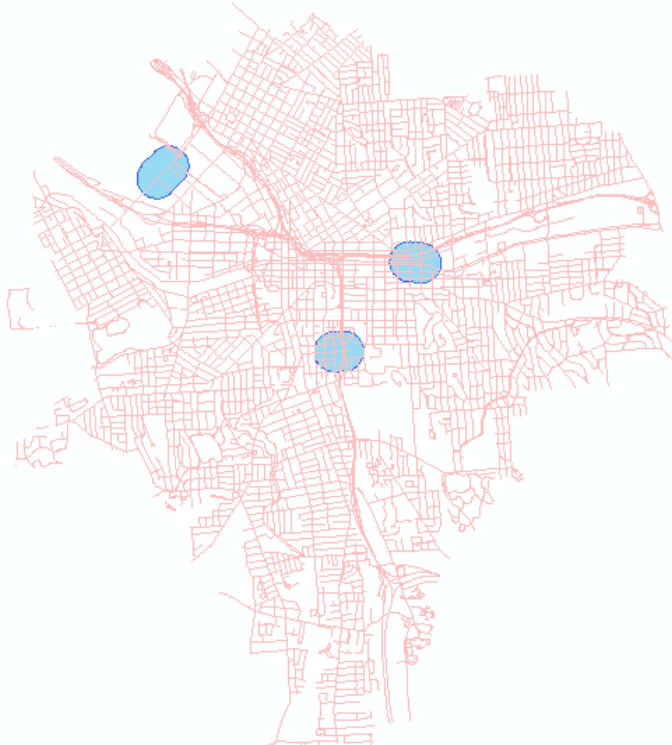
Energy Consumption Value:

- 7,758,200 (MJ per 1 lane km) x 1.198 lane km = **9,294,324 MJ**

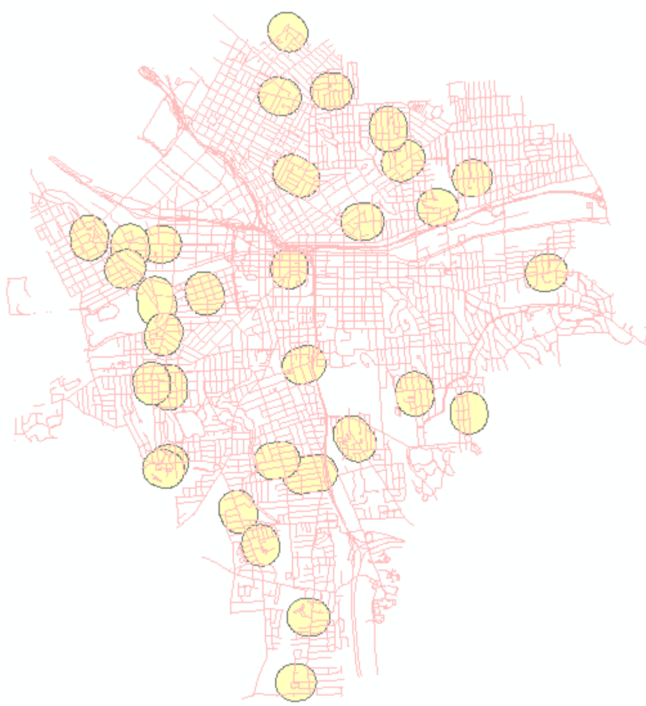
Table A-1. Top Ten Employers in Syracuse and Their Corresponding Total Workforces

Rank	Employer Name	Number of Employees
1	Upstate University Health System	9,525
2	Syracuse University	4,621
3	St. Joseph's Hospital Health Center	3,745
4	Wegmans	3,713
5	Crouse Hospital	2,700
6	Loretto	2,476
7	Lockheed Martin MS2	2,250
8	National Grid	2,000
9	Spectrum	1,800
10	Raymour & Flanigan	1,400

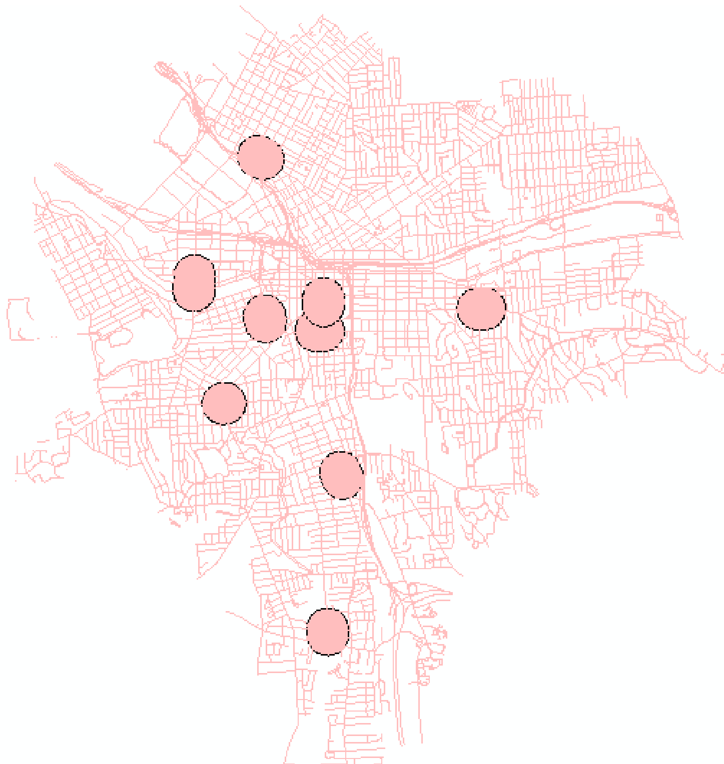
Buffers Indicating Locations of Critical Objects



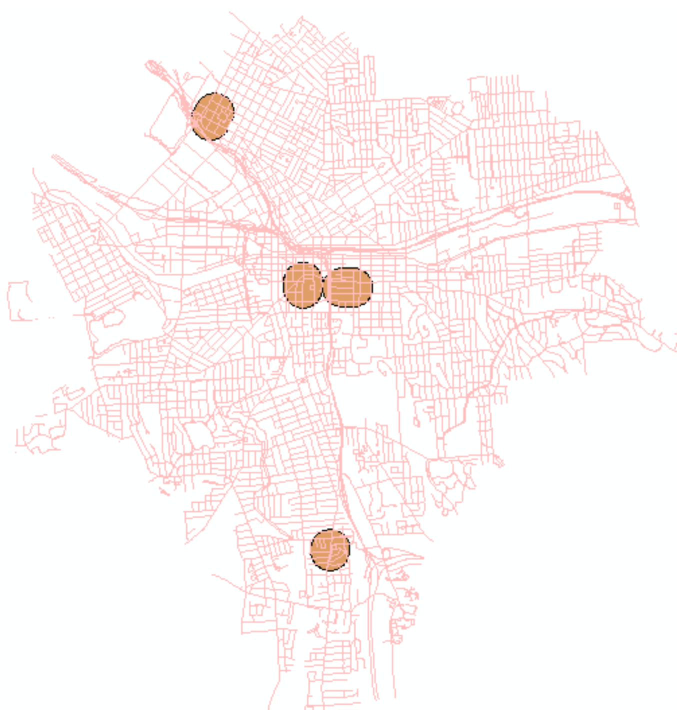
Water Supply Station Locations



Public School Locations

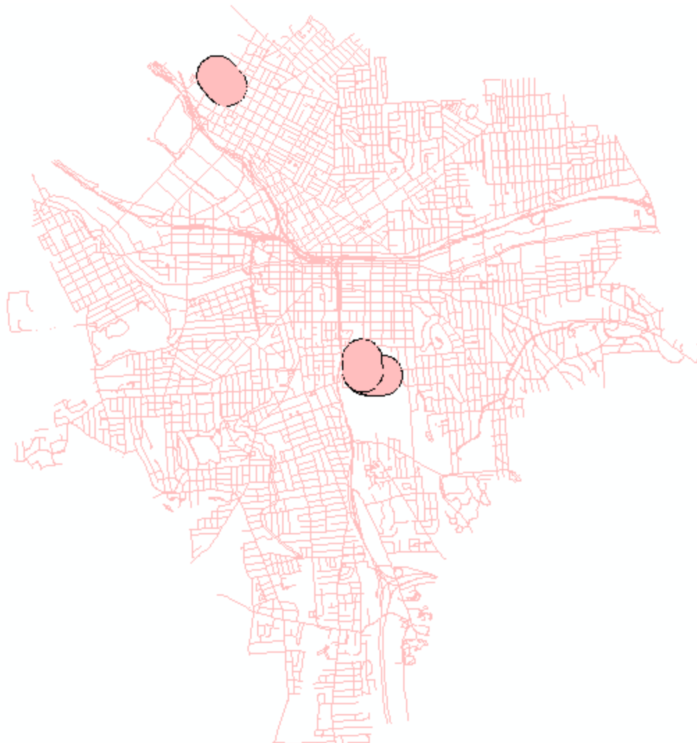


Fire Station Locations

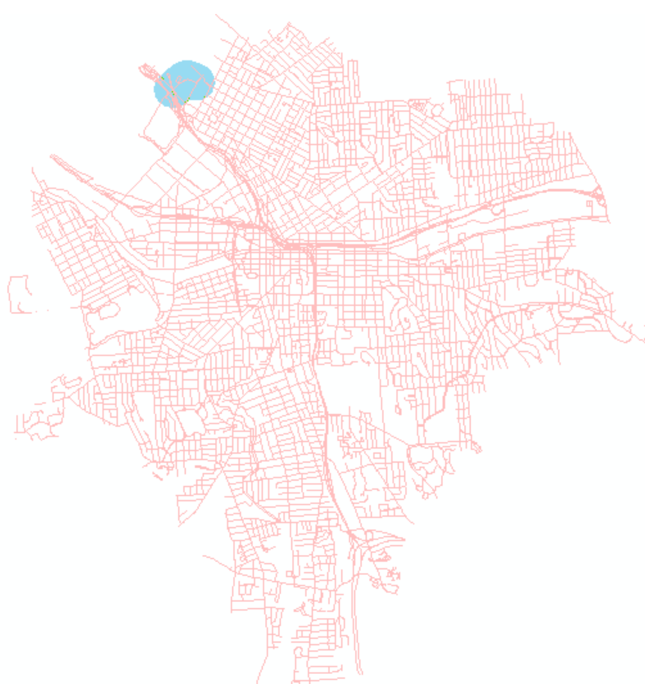


Police Station Locations

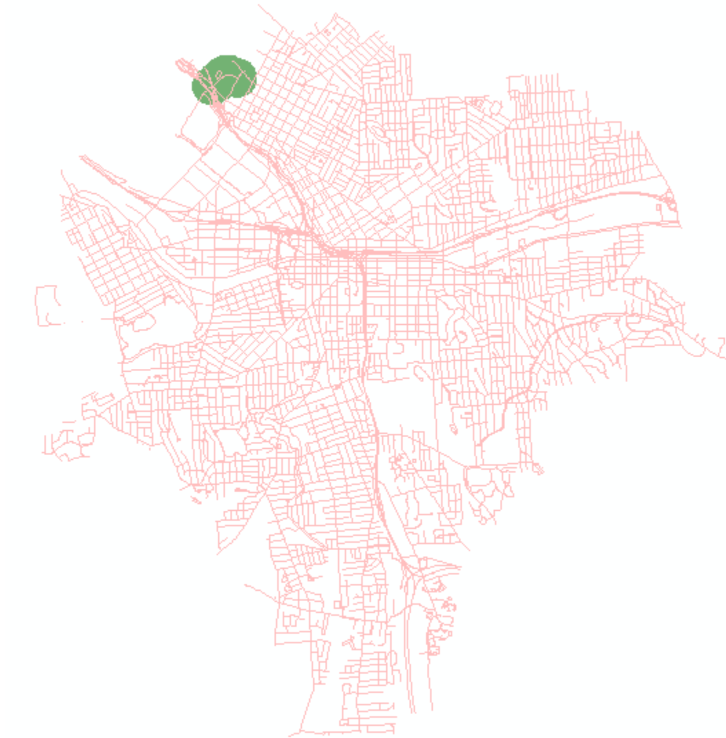
Buffers Indicating Locations of Other Public Objects



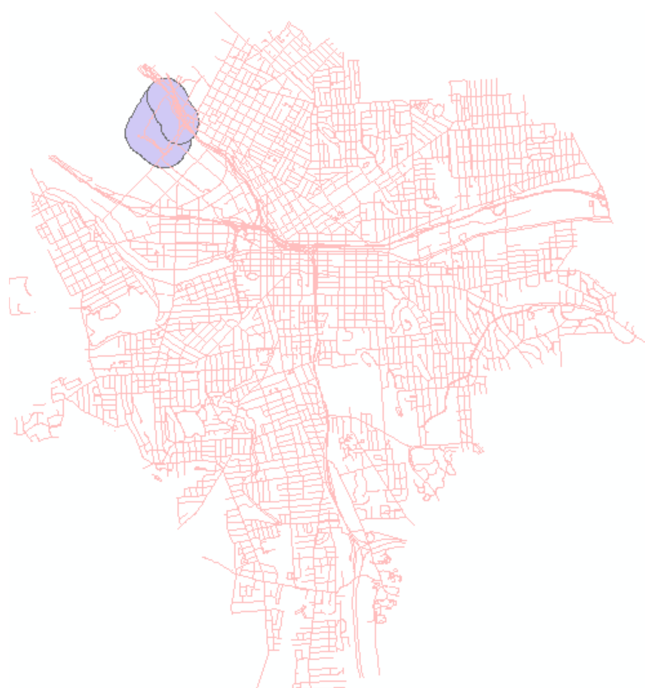
Stadium Locations



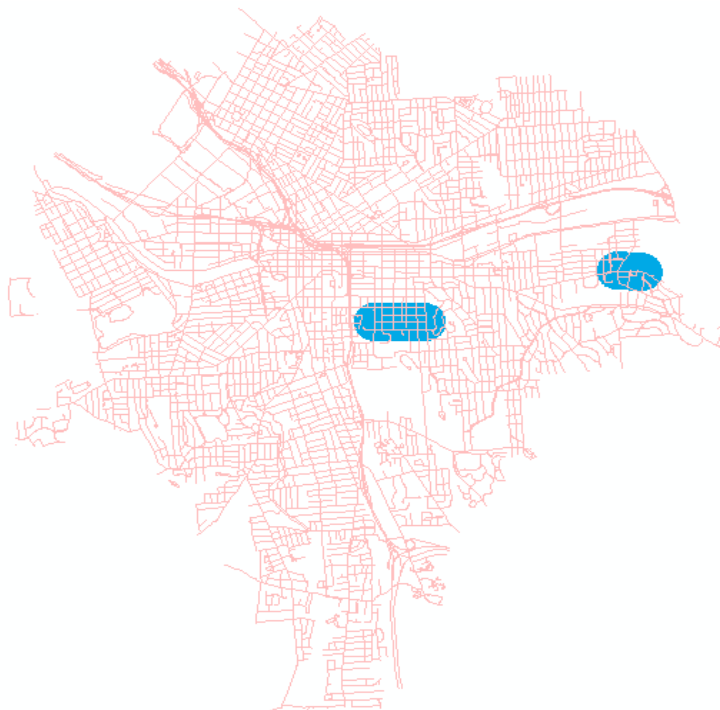
Regional Transportation Center



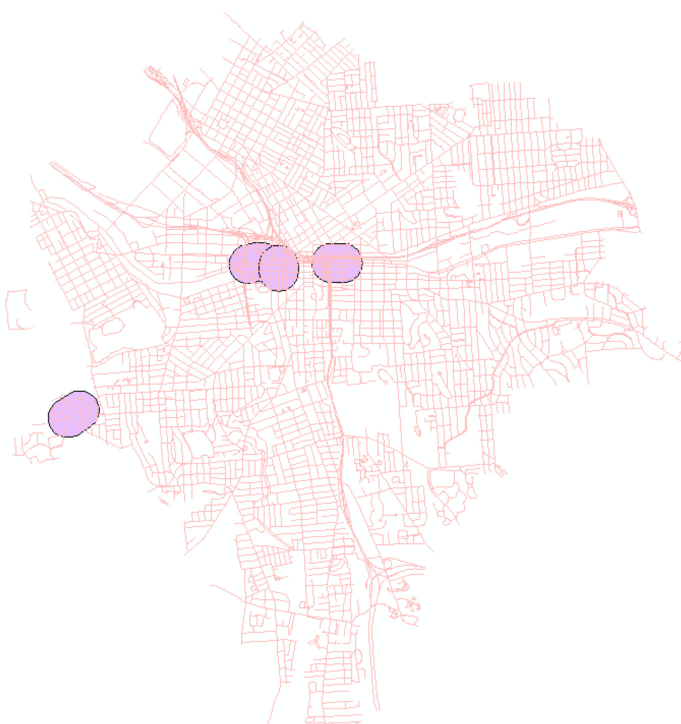
Train Station Location



Mall Location



University Locations



Top Employers Locations

Appendix B:

Questionnaire Distributed to City Employees

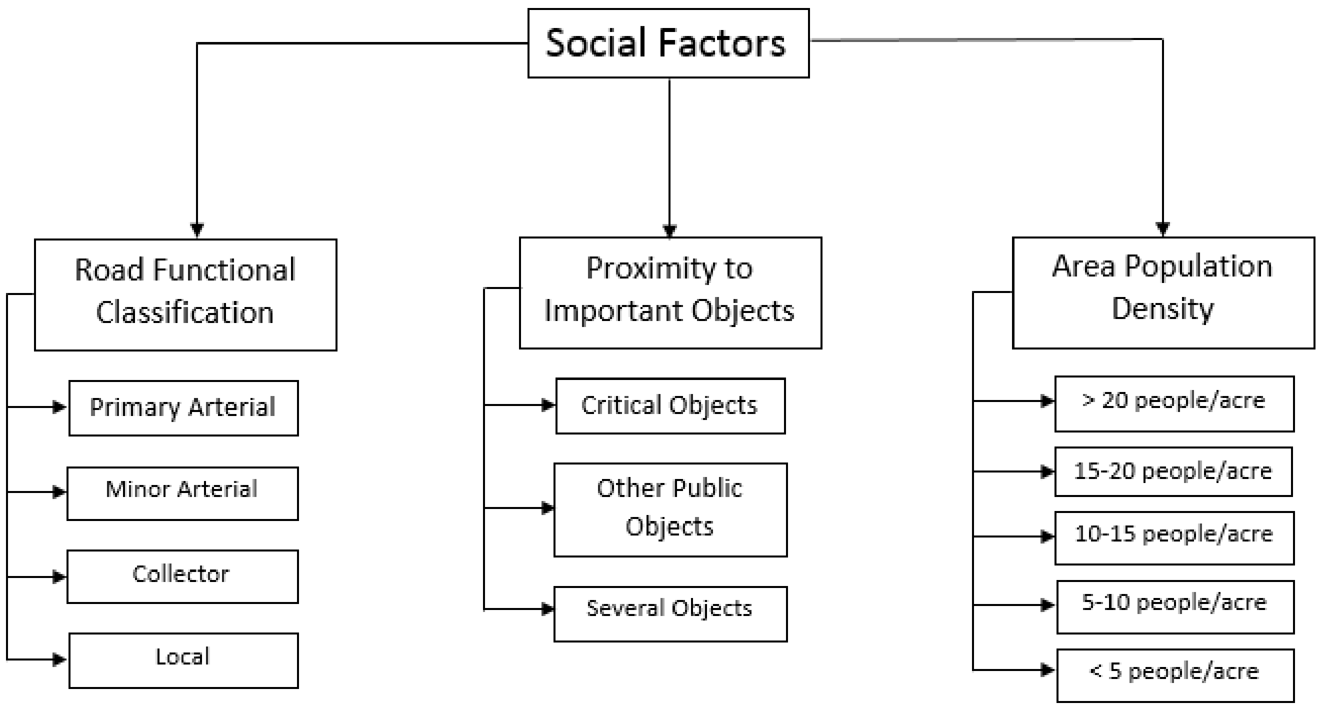
This set of questions was designed to improve the analysis method that is currently used for the prioritization of Syracuse roadways in an ongoing research performed by the Department of Civil and Environmental Engineering at Syracuse University.

The research aims to prioritize the streets within the City of Syracuse based on a variety of factors in order to assign risk values to every road segment. Currently, roads are primarily evaluated based on their **current condition ratings** that are assigned by field inspectors. This research focuses on adding an additional **level of importance factors** that can work together with the **current condition ratings** to prioritize the roads.

The Importance Level includes three categories of factors that can be assigned to roadways: **Social**, **Economic** and **Environmental.** Based on your experience in the field and the information provided, please answer the following questions regarding weight factors that can be assigned to each category.

Serviceability Limit (Roadway Failure) in this research means that the road is not in an adequate condition to drive on and the only option to improve it is **total reconstruction**.

The following figure represents sub-categories that are included in the **Social** category.



- **Road Functional Classification** describes what class of road is assigned to a particular roadway.

- **Proximity to Important Objects** describes how many important objects are close to a roadway. **Critical Objects** include hospitals, police stations etc. **Other Public Objects** include stadiums, universities, malls etc. **Several Objects** mean that a roadway is close to more than two of the objects mentioned before.

- **Area Population Density** describes how many people live in the neighborhood where the road is located.

Question 1

Please assign weight factors to each social sub-category to assess their importance when prioritizing roads. The sum of weights needs to be equal to 1.

(Ex. **Road Functional Classification** = 0.25; **Proximity to Important Objects** = 0.25; **Area Population Density** = 0.5; **Sum** = 0.25 + 0.25 + 0.5 = 1)

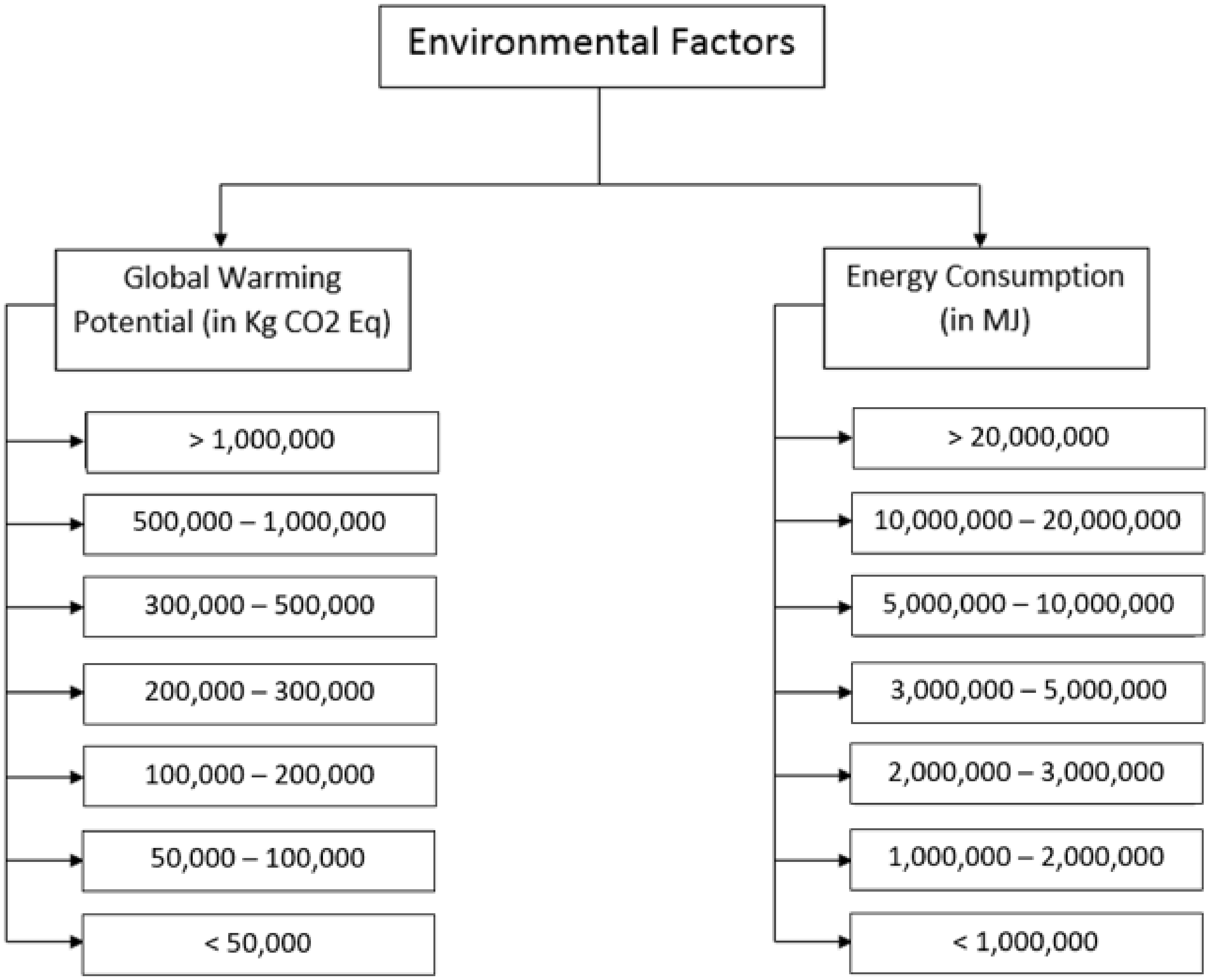
<u>Now, please enter your weights for:</u>

Road Functional Classification =

Proximity to Important Objects =

Area Population Density =

The following figure represents sub-categories under the **Environmental** factors



Environmental factors describe environmental consequences of roadway reconstruction in case of failure.

- **Global Warming Potential** describes how many kilograms of CO_2 will be produced if a road fails and needs to be reconstructed
- **Energy Consumption** describes how much energy in MegaJoules will be used during the reconstruction process.

Question 2

Following the same logic as previously, assign weights to the **Environmental** sub-categories. The sum of weights needs to be equal to 1.

(Ex. **Global Warming Potential** = 0.5; **Energy Consumption** = 0.5; **Sum** = 0.5 + 0.5 = 1)

<u>Now, please enter your weights for:</u>

Global Warming Potential =

Energy Consumption =

Question 3

After assigning weights to all sub-categories in **social**, **economic** and **environmental** groups, please assign weights to these groups to assess their importance on a larger scale. The sum of weights needs to be equal to 1.

(Ex. **Social** = 0.4; **Economic** = 0.5; **Environmental** = 0.1; **Sum** = 0.4 + 0.5 + 0.1 = 1)

<u>Now, please enter your weights for:</u>

Social =

Economic =

Environmental =

Appendix C:

Results of the Analysis with Equal Weights

Table C-1: Top Road Segments with the Lowest Social Ratings

Number	Street ID	Street Name	Street Type	Street Classification	Class Rank	Proximity to Objects Rank	Population Density Rank	Overall
1	12575193	HIAWATHA	BLVD	MA	2	1	1	1.33
2	12575227	HIAWATHA	BLVD	MA	2	1	1	1.33
3	12575231	SALINA	ST	MA	2	1	1	1.33
4	12575233	HIAWATHA	BLVD	MA	2	1	1	1.33
5	12575234	SALINA	ST	MA	2	1	1	1.33
6	12575242	HIAWATHA	BLVD	MA	2	1	1	1.33
7	12575244	HIAWATHA	BLVD	MA	2	1	1	1.33
8	12575263	WOLF	ST	MA	2	1	1	1.33
9	12575475	HIAWATHA	BLVD	MA	2	1	1	1.33
10	12575478	HIAWATHA	BLVD	MA	2	1	1	1.33
11	12575479	WOLF	ST	MA	2	1	1	1.33
12	12577798	GENESEE	ST	PA	1	1	2	1.33
13	12577807	GENESEE	ST	PA	1	1	2	1.33
14	12577809	GENESEE	ST	PA	1	1	2	1.33
15	12577812	GENESEE	ST	PA	1	1	2	1.33
16	12577813	GENESEE	ST	PA	1	1	2	1.33
17	12578129	GENESEE	ST	PA	1	1	2	1.33
18	12578132	GENESEE	ST	PA	1	1	2	1.33
19	13017762	GENESEE	ST	PA	1	1	2	1.33
20	13018251	HIAWATHA	BLVD	MA	2	1	1	1.33
21	12577922	JAMES	ST	PA	1	2	1	1.33
22	12577970	JAMES	ST	PA	1	2	1	1.33
23	13008649	JAMES	ST	PA	1	2	1	1.33
24	12576856	BRIGHTON	AVE	PA	1	1	3	1.67
25	12577434	RENWICK	AVE	MA	2	1	2	1.67
26	12577436	RENWICK	AVE	MA	2	1	2	1.67
27	12577437	RENWICK	AVE	MA	2	1	2	1.67
28	12577463	RENWICK	AVE	MA	2	1	2	1.67
29	12577464	VAN BUREN	ST	MA	2	1	2	1.67
30	12577465	VAN BUREN	ST	MA	2	1	2	1.67
31	12577489	VAN BUREN	ST	MA	2	1	2	1.67
32	12577490	IRVING	AVE	MA	2	1	2	1.67
33	12577749	HARRISON	ST	MA	2	1	2	1.67
34	12577750	IRVING	AVE	MA	2	1	2	1.67
35	12577753	ADAMS	ST	MA	2	1	2	1.67
36	12577755	ADAMS	ST	MA	2	1	2	1.67
37	12577759	IRVING	AVE	MA	2	1	2	1.67
38	12577761	HARRISON	ST	MA	2	1	2	1.67
39	12577762	HARRISON	ST	MA	2	1	2	1.67
40	12577763	IRVING	AVE	MA	2	1	2	1.67

41	12577765	HARRISON	ST	MA	2	1	2	1.67
42	12577802	FAYETTE	ST	MA	2	1	2	1.67
43	12577806	IRVING	AVE	MA	2	1	2	1.67
44	12577808	IRVING	AVE	MA	2	1	2	1.67
45	12577817	FAYETTE	ST	MA	2	1	2	1.67
46	12577820	FAYETTE	ST	MA	2	1	2	1.67
47	12578107	UNIVERSITY	AVE	MA	2	1	2	1.67
48	12578108	HARRISON	ST	MA	2	1	2	1.67
49	12578110	UNIVERSITY	AVE	MA	2	1	2	1.67
50	12578128	UNIVERSITY	AVE	MA	2	1	2	1.67
51	12578135	FAYETTE	ST	MA	2	1	2	1.67
52	13001962	IRVING	AVE	MA	2	1	2	1.67
53	13008612	BURT	ST	MA	2	1	2	1.67
54	13018654	IRVING	AVE	MA	2	1	2	1.67
55	13018814	IRVING	AVE	MA	2	1	2	1.67
56	12575200	SALINA	ST	MA	2	2	1	1.67
57	12575221	SALINA	ST	MA	2	2	1	1.67
58	12575222	SALINA	ST	MA	2	2	1	1.67
59	12575235	WOLF	ST	MA	2	2	1	1.67
60	12575249	WOLF	ST	MA	2	2	1	1.67
61	12575517	GRANT	BLVD	MA	2	2	1	1.67
62	12577779	GENESEE	ST	PA	1	2	2	1.67
63	12577894	ERIE	BLVD	PA	1	2	2	1.67
64	12577920	BURNET	AVE	MA	2	2	1	1.67
65	12577921	BURNET	AVE	MA	2	2	1	1.67
66	12577933	BURNET	AVE	MA	2	2	1	1.67
67	12578147	GENESEE	ST	PA	1	2	2	1.67
68	12578148	GENESEE	ST	PA	1	2	2	1.67
69	12578236	ERIE	BLVD	PA	1	2	2	1.67
70	12578246	LODI	ST	MA	2	2	1	1.67
71	12578247	LODI	ST	MA	2	2	1	1.67
72	12580555	GRANT	BLVD	MA	2	2	1	1.67
73	13001803	LODI	ST	MA	2	2	1	1.67
74	13011835	BURNET	AVE	MA	2	2	1	1.67
75	13017763	GENESEE	ST	PA	1	2	2	1.67

Table C-2: Top Road Segments with the Highest Reconstruction Costs

Number	Street ID	Street Name	Street Type	Street Classification	Reconstruction Cost ($)
1	12578849	ERIE	BLVD	PA	1,105,251
2	12579028	ERIE	BLVD	PA	1,089,975
3	12579670	ERIE	BLVD	PA	1,089,975
4	12577509	COMSTOCK	AVE	MA	1,050,047
5	12577557	COMSTOCK	AVE	MA	1,050,047
6	12575064	BEAR	ST	MA	718,245
7	13020311	BEAR	ST	MA	718,245
8	12575227	HIAWATHA	BLVD	MA	711,568
9	12575193	HIAWATHA	BLVD	MA	668,443
10	13018251	HIAWATHA	BLVD	MA	668,443
11	12576905	BRIGHTON	AVE	MA	628,746
12	12576908	BRIGHTON	AVE	MA	628,746
13	13016734	BRIGHTON	AVE	MA	628,746
14	13016736	BRIGHTON	AVE	MA	628,746
15	12579379	GENESEE	ST	PA	623,346
16	12574897	ERIE	BLVD	PA	604,702
17	12575022	HIAWATHA	BLVD	MA	595,130
18	12575240	PARK	ST	Local	586,945
19	12577016	COLVIN	ST	MA	584,101
20	12577017	COLVIN	ST	MA	584,101
21	12577020	COLVIN	ST	MA	584,101
22	12573581	SHONNARD	ST	CO	576,960
23	12572856	EMERSON	AVE	Local	570,167
24	12572949	ROBERTS	AVE	Local	561,667
25	13002183	ROBERTS	AVE	Local	561,667
26	12575069	SOLAR	ST	Local	541,136
27	12577133	COLVIN	ST	MA	536,491
28	12573449	ERIE	BLVD	Local	525,084
29	12578368	MEADOWBROOK	DR	Local	524,492
30	13002087	MEADOWBROOK	DR	Local	524,492
31	12578853	MIDLER	AVE	Local	519,455
32	12580957	MIDLER	AVE	Local	519,455
33	13001807	MIDLER	AVE	Local	519,455
34	13001808	MIDLER	AVE	Local	519,455
35	13011157	MIDLER	AVE	Local	519,455
36	13011158	MIDLER	AVE	Local	519,455
37	13013140	SEYMOUR	ST	CO	509,617
38	12578831	ERIE	BLVD	PA	498,746
39	13011156	ERIE	BLVD	PA	498,746
40	12578827	ERIE	BLVD	PA	480,580
41	12578828	ERIE	BLVD	PA	480,580
42	12581000	SHOTWELL	PARK	Local	479,216
43	13010341	SHOTWELL	PARK	Local	479,216
44	13010342	SHOTWELL	PARK	Local	479,216
45	12580574	ROSS	PARK	Local	478,434
46	13002015	BRIGHTON	AVE	MA	476,611
47	13002017	BRIGHTON	AVE	MA	476,611
48	13002018	BRIGHTON	AVE	MA	476,611
49	13002032	BRIGHTON	AVE	MA	476,611
50	13028153	BRIGHTON	AVE	MA	476,611
51	12575065	SOLAR	ST	Local	450,559

52	12573022	GRAND	AVE	MA	448,209
53	12573758	PARK	AVE	Local	444,176
54	12573759	PARK	AVE	Local	444,176
55	13010444	PARK	AVE	Local	444,176
56	12571879	GEDDES	ST	MA	444,173
57	12574992	BEAR	ST	MA	442,629
58	12575005	BEAR	ST	MA	442,143
59	13020312	BEAR	ST	MA	442,143
60	12574993	PULASKI	ST	Local	440,802
61	13020313	HIAWATHA	BLVD	MA	440,038
62	13020314	HIAWATHA	BLVD	MA	440,038
63	12575007	VAN RENSSELAER	ST	Local	439,818
64	12575011	VAN RENSSELAER	ST	Local	439,818
65	12573507	ERIE	BLVD	PA	435,463
66	12573509	STATE FAIR	BLVD	CO	428,775
67	12571904	SOUTH	AVE	MA	423,413
68	12581006	GRANT	BLVD	MA	416,893
69	12581012	GRANT	BLVD	MA	416,893
70	13001229	GRANT	BLVD	MA	416,893
71	13006125	GRANT	BLVD	MA	416,893
72	13006126	GRANT	BLVD	MA	416,893
73	13006127	GRANT	BLVD	MA	416,893
74	12580093	JAMES	ST	PA	414,304
75	13028396	JAMES	ST	PA	414,304
76	13028397	JAMES	ST	PA	414,304
77	12573862	ERIE	BLVD	PA	402,548
78	12577580	COMSTOCK	AVE	MA	401,324
79	12577749	HARRISON	ST	MA	400,812
80	12577761	HARRISON	ST	MA	400,812
81	12577762	HARRISON	ST	MA	400,812
82	12575246	WASHINGTON	SQ	Local	400,594
83	12575254	WASHINGTON	SQ	Local	400,594
84	12575256	WASHINGTON	SQ	Local	400,594
85	12576554	SALINA	ST	MA	396,674
86	12577256	FURMAN	ST	Local	394,002
87	12575047	VAN RENSSELAER	ST	Local	393,949
88	12579024	ERIE	BLVD	PA	392,639
89	13011164	ERIE	BLVD	PA	392,639
90	12576831	WEBSTER	AVE	Local	391,301
91	12577700	TOWNSEND	ST	CO	390,386
92	12577709	TOWNSEND	ST	CO	390,386
93	12573197	KENNEDY	ST	Local	388,205
94	12573380	COLERIDGE	AVE	Local	386,510
95	13010429	COLERIDGE	AVE	Local	386,510
96	12573668	ONONDAGA	ST	MA	386,014
97	13002344	ONONDAGA	ST	MA	386,014
98	13020292	ONONDAGA	ST	MA	386,014
99	13020293	ONONDAGA	ST	MA	386,014
100	12578746	GENESEE	ST	PA	385,341

Table C-3: Top Road Segments with the Lowest Environmental Ratings

Number	Street ID	Street Name	Street Type	GWP Rating	Energy Consumption Rating	Overall
1	12577509	COMSTOCK	AVE	1	1	1
2	12577557	COMSTOCK	AVE	1	1	1
3	12578849	ERIE	BLVD	1	1	1
4	12579028	ERIE	BLVD	1	1	1
5	12579670	ERIE	BLVD	1	1	1
6	12575064	BEAR	ST	1	2	1.5
7	12575227	HIAWATHA	BLVD	1	2	1.5
8	13020311	BEAR	ST	1	2	1.5
9	12572856	EMERSON	AVE	2	2	2
10	12572949	ROBERTS	AVE	2	2	2
11	12573581	SHONNARD	ST	2	2	2
12	12574897	ERIE	BLVD	3	1	2
13	12574992	BEAR	ST	2	2	2
14	12575005	BEAR	ST	2	2	2
15	12575022	HIAWATHA	BLVD	2	2	2
16	12575069	SOLAR	ST	2	2	2
17	12575193	HIAWATHA	BLVD	2	2	2
18	12575240	PARK	ST	2	2	2
19	12576905	BRIGHTON	AVE	3	1	2
20	12576908	BRIGHTON	AVE	3	1	2
21	12577016	COLVIN	ST	2	2	2
22	12577017	COLVIN	ST	2	2	2
23	12577020	COLVIN	ST	2	2	2
24	12577133	COLVIN	ST	2	2	2
25	12578368	MEADOWBROOK	DR	2	2	2
26	12578827	ERIE	BLVD	2	2	2
27	12578828	ERIE	BLVD	2	2	2
28	12578831	ERIE	BLVD	2	2	2
29	12578853	MIDLER	AVE	2	2	2
30	12579379	GENESEE	ST	2	2	2
31	12580957	MIDLER	AVE	2	2	2
32	12581000	SHOTWELL	PARK	2	2	2
33	13001807	MIDLER	AVE	2	2	2
34	13001808	MIDLER	AVE	2	2	2
35	13002087	MEADOWBROOK	DR	2	2	2
36	13002183	ROBERTS	AVE	2	2	2
37	13010341	SHOTWELL	PARK	2	2	2
38	13010342	SHOTWELL	PARK	2	2	2
39	13011156	ERIE	BLVD	2	2	2
40	13011157	MIDLER	AVE	2	2	2
41	13011158	MIDLER	AVE	2	2	2
42	13013140	SEYMOUR	ST	2	2	2
43	13016734	BRIGHTON	AVE	3	1	2
44	13016736	BRIGHTON	AVE	3	1	2
45	13018251	HIAWATHA	BLVD	2	2	2
46	13020312	BEAR	ST	2	2	2
47	12571879	GEDDES	ST	2	3	2.5
48	12571904	SOUTH	AVE	2	3	2.5
49	12573022	GRAND	AVE	2	3	2.5
50	12573449	ERIE	BLVD	3	2	2.5
51	12573507	ERIE	BLVD	2	3	2.5

52	12573509	STATE FAIR	BLVD	2	3	2.5
53	12573668	ONONDAGA	ST	2	3	2.5
54	12573737	SALINA	ST	2	3	2.5
55	12573758	PARK	AVE	2	3	2.5
56	12573759	PARK	AVE	2	3	2.5
57	12573862	ERIE	BLVD	2	3	2.5
58	12573955	SALINA	ST	2	3	2.5
59	12574993	PULASKI	ST	2	3	2.5
60	12575007	VAN RENSSELAER	ST	2	3	2.5
61	12575011	VAN RENSSELAER	ST	2	3	2.5
62	12575047	VAN RENSSELAER	ST	2	3	2.5
63	12575065	SOLAR	ST	2	3	2.5
64	12576554	SALINA	ST	2	3	2.5
65	12576788	BRIGHTON	AVE	3	2	2.5
66	12577340	SALINA	ST	2	3	2.5
67	12577580	COMSTOCK	AVE	2	3	2.5
68	12577749	HARRISON	ST	2	3	2.5
69	12577761	HARRISON	ST	2	3	2.5
70	12577762	HARRISON	ST	2	3	2.5
71	12577944	SALINA	ST	2	3	2.5
72	12577955	SALINA	ST	2	3	2.5
73	12578036	ERIE	BLVD	2	3	2.5
74	12578746	GENESEE	ST	2	3	2.5
75	12579024	ERIE	BLVD	2	3	2.5
76	12580093	JAMES	ST	2	3	2.5
77	12580574	ROSS	PARK	2	3	2.5
78	12580928	SHOTWELL	PARK	2	3	2.5
79	12581006	GRANT	BLVD	2	3	2.5
80	12581012	GRANT	BLVD	2	3	2.5
81	13001229	GRANT	BLVD	2	3	2.5
82	13002015	BRIGHTON	AVE	3	2	2.5
83	13002017	BRIGHTON	AVE	3	2	2.5
84	13002018	BRIGHTON	AVE	3	2	2.5
85	13002032	BRIGHTON	AVE	3	2	2.5
86	13002344	ONONDAGA	ST	2	3	2.5
87	13006125	GRANT	BLVD	2	3	2.5
88	13006126	GRANT	BLVD	2	3	2.5
89	13006127	GRANT	BLVD	2	3	2.5
90	13010337	SHOTWELL	PARK	2	3	2.5
91	13010338	SHOTWELL	PARK	2	3	2.5
92	13010444	PARK	AVE	2	3	2.5
93	13011164	ERIE	BLVD	2	3	2.5
94	13018179	SALINA	ST	2	3	2.5
95	13020292	ONONDAGA	ST	2	3	2.5
96	13020293	ONONDAGA	ST	2	3	2.5
97	13020313	HIAWATHA	BLVD	2	3	2.5
98	13020314	HIAWATHA	BLVD	2	3	2.5
99	13028153	BRIGHTON	AVE	3	2	2.5
100	13028396	JAMES	ST	2	3	2.5

Table C-4: Top Road Segments Based on Their Condition Ratings

Number	Street ID	Street Name	Street Type	Street Classification	Overall Current Condition Rating
1	12577562	OSTROM	PL	Local	1
2	12571899	PALMER	LN	Local	2
3	12572016	HILLVIEW	AVE	Local	2
4	12572106	KIRK PARK	DR	Parks	2
5	12572989	HUBBELL	AVE	Local	2
6	12573140	CRESCENT	AVE	Local	2
7	12573182	CRESCENT	AVE	Local	2
8	12573183	CRESCENT	AVE	Local	2
9	12573444	NELSON	ST	Local	2
10	12573673	ONEIDA	ST	Local	2
11	12574852	KANE	RD	Local	2
12	12575001	GEDDES	ST	Local	2
13	12575226	PARK	ST	CO	2
14	12575236	EXCHANGE	ST	Local	2
15	12575284	PARK	ST	CO	2
16	12577291	COLVIN	ST	Local	2
17	12577333	ALEXANDER	AVE	Local	2
18	12577390	BURT	ST	MA	2
19	12577708	LANDMARK	PL	Local	2
20	12578043	CROUSE	AVE	Local	2
21	12578051	CROUSE	AVE	Local	2
22	12578052	CROUSE	AVE	Local	2
23	12578056	CROUSE	AVE	Local	2
24	12578124	HARRISON	ST	Local	2
25	12578532	JANET	DR	Local	2
26	12578654	HARRINGTON	RD	Local	2
27	12578658	HARRINGTON	RD	Local	2
28	12578695	SCOTTHOLM	TER	Local	2
29	12578715	CROLY	ST	Local	2
30	12579997	PROSPECT	AVE	Local	2
31	12580050	STRAND	PL	Local	2
32	12580075	HIGHLAND	ST	Local	2
33	12580097	DOUGLAS	ST	Local	2
34	12580110	CARBON	ST	Local	2
35	12580337	JASPER	ST	Local	2
36	12580453	RUGBY	RD	Local	2
37	12580494	WENDELL	TER	Local	2
38	13002046	COLVIN	ST	Local	2
39	13013186	CROUSE	AVE	Local	2
40	13013188	CROUSE	AVE	Local	2
41	13013256	HARRINGTON	RD	Local	2
42	13017690	COLVIN	ST	Local	2
43	13029619	ONEIDA	ST	Local	2
44	12571858	STINARD	AVE	Local	3
45	12571862	WELLESLEY	RD	Local	3
46	12571870	STINARD	AVE	Local	3
47	12571881	STINARD	AVE	Local	3
48	12571888	COLVIN	ST	Local	3
49	12571949	GIRARD	AVE	Local	3
50	12571967	NEWELL	ST	Local	3
51	12571973	NEWELL	ST	Local	3

52	12572024	HILLVIEW	AVE	Local	3
53	12572025	HILLVIEW	AVE	Local	3
54	12572030	COLVIN	ST	Local	3
55	12572070	HILLVIEW	AVE	Local	3
56	12572089	KIRK PARK	DR	Parks	3
57	12572091	EDMUND	AVE	Local	3
58	12572105	KIRK PARK	DR	Parks	3
59	12572117	RANDALL	AVE	Local	3
60	12572131	KIRK PARK	DR	Parks	3
61	12572143	KIRK PARK	DR	Parks	3
62	12572709	AVOCA	ST	Local	3
63	12572960	GORDON	AVE	Local	3
64	12573202	KIRK	AVE	Local	3
65	12573216	DEARBORN	PL	Local	3
66	12573334	OXFORD	ST	Local	3
67	12573363	ONEIDA	ST	Local	3
68	12573376	ONEIDA	ST	Local	3
69	12573528	WALL	ST	Local	3
70	12573616	SENECA	ST	Local	3
71	12573622	TRACY	ST	Local	3
72	12573713	MARCELLUS	ST	Local	3
73	12574889	STATE FAIR	BLVD	Local	3
74	12574976	STATE FAIR	BLVD	Local	3
75	12574981	STATE FAIR	BLVD	Local	3
76	12575092	CLINTON	ST	Local	3
77	12575095	CLINTON	ST	Local	3
78	12575102	DIVISION	ST	Local	3
79	12575110	STATE	ST	MA	3
80	12575112	STATE	ST	MA	3
81	12575113	STATE	ST	MA	3
82	12575148	SUNSET	AVE	Local	3
83	12575233	HIAWATHA	BLVD	MA	3
84	12575234	SALINA	ST	MA	3
85	12575242	HIAWATHA	BLVD	MA	3
86	12575243	CARBON	ST	Local	3
87	12575244	HIAWATHA	BLVD	MA	3
88	12575252	CARBON	ST	Local	3
89	12575253	PARK	ST	CO	3
90	12575259	CARBON	ST	Local	3
91	12575260	CARBON	ST	Local	3
92	12575261	CARBON	ST	Local	3
93	12575278	DANFORTH	ST	Local	3
94	12575293	PARK	ST	CO	3
95	12575296	CARBON	ST	Local	3
96	12576620	SENECA	DR	Local	3
97	12576651	SPRINGBROOK	AVE	Local	3
98	12576800	NEWELL	ST	Local	3
99	12576804	NEWELL	ST	Local	3
100	12576845	PLEASANT	AVE	Local	3

Ranking Results of the Analysis with Assigned Weights (Primary Analysis)

Table C-5: Top 100 Road Segments with Highest Overall Importance Scores

Number	Street ID	Street Name	Street Type	Weighted Social	Weighted Economic	Weighted Environmental	Overall Importance
1	12579670	ERIE	BLVD	42.65	32	13.00	**87.65**
2	12577509	COMSTOCK	AVE	36.05	32	10.99	**79.04**
3	12577557	COMSTOCK	AVE	36.05	32	10.99	**79.04**
4	12578849	ERIE	BLVD	32.81	32	13.00	**77.81**
5	12579028	ERIE	BLVD	32.81	32	13.00	**77.81**
6	12579379	GENESEE	ST	35.78	24	13.00	**72.78**
7	12575193	HIAWATHA	BLVD	39.02	24	9.50	**72.53**
8	13016734	BRIGHTON	AVE	39.02	24	9.50	**72.53**
9	13016736	BRIGHTON	AVE	39.02	24	9.50	**72.53**
10	13018251	HIAWATHA	BLVD	39.02	24	9.50	**72.53**
11	13020311	BEAR	ST	39.02	24	9.50	**72.53**
12	12574897	ERIE	BLVD	32.81	24	13.00	**69.81**
13	12576905	BRIGHTON	AVE	36.05	24	9.50	**69.56**
14	12576908	BRIGHTON	AVE	36.05	24	9.50	**69.56**
15	12573562	GENESEE	ST	45.62	12.8	9.50	**67.93**
16	12573791	GENESEE	ST	45.62	12.8	9.50	**67.93**
17	12577779	GENESEE	ST	45.62	12.8	9.50	**67.93**
18	12577798	GENESEE	ST	45.62	12.8	9.50	**67.93**
19	12577020	COLVIN	ST	36.52	24	6.28	**66.80**
20	12578828	ERIE	BLVD	42.65	12.8	10.99	**66.44**
21	12577016	COLVIN	ST	36.05	24	6.28	**66.33**
22	12577017	COLVIN	ST	36.05	24	6.28	**66.33**
23	12578746	GENESEE	ST	42.65	12.8	9.50	**64.96**
24	12578781	ERIE	BLVD	42.65	12.8	9.50	**64.96**
25	12578782	ERIE	BLVD	42.65	12.8	9.50	**64.96**
26	12578783	ERIE	BLVD	42.65	12.8	9.50	**64.96**
27	12580093	JAMES	ST	42.65	12.8	9.50	**64.96**
28	12580320	JAMES	ST	42.65	12.8	9.50	**64.96**
29	12575022	HIAWATHA	BLVD	29.18	24	9.50	**62.68**
30	12575064	BEAR	ST	29.18	24	9.50	**62.68**
31	12575227	HIAWATHA	BLVD	29.18	24	9.50	**62.68**
32	12577133	COLVIN	ST	32.15	24	6.28	**62.43**
33	12578731	GENESEE	ST	42.65	12.8	6.28	**61.73**
34	13002015	BRIGHTON	AVE	39.02	12.8	9.50	**61.33**
35	13002017	BRIGHTON	AVE	39.02	12.8	9.50	**61.33**
36	13002018	BRIGHTON	AVE	39.02	12.8	9.50	**61.33**
37	13002032	BRIGHTON	AVE	39.02	12.8	9.50	**61.33**
38	13028153	BRIGHTON	AVE	39.02	12.8	9.50	**61.33**
39	12573507	ERIE	BLVD	38.75	12.8	9.50	**61.05**
40	12573623	ERIE	BLVD	38.75	12.8	9.50	**61.05**
41	12577922	JAMES	ST	42.65	8	9.50	**60.16**
42	12578795	ERIE	BLVD	42.65	8	9.50	**60.16**
43	12573884	ERIE	BLVD	45.62	8	6.28	**59.90**
44	12577357	STATE	ST	45.62	8	6.28	**59.90**
45	12577807	GENESEE	ST	45.62	8	6.28	**59.90**
46	13002509	STATE	ST	45.62	8	6.28	**59.90**
47	13002381	ERIE	BLVD	35.78	12.8	10.99	**59.56**

48	13011156	ERIE	BLVD	35.78	12.8	10.99	**59.56**
49	13013140	SEYMOUR	ST	28.52	24	6.28	**58.80**
50	12573449	ERIE	BLVD	28.33	24	6.28	**58.60**
51	13002344	ONONDAGA	ST	39.02	12.8	6.28	**58.10**
52	13018179	SALINA	ST	39.02	12.8	6.28	**58.10**
53	13020292	ONONDAGA	ST	39.02	12.8	6.28	**58.10**
54	13020293	ONONDAGA	ST	39.02	12.8	6.28	**58.10**
55	13020313	HIAWATHA	BLVD	39.02	12.8	6.28	**58.10**
56	13020314	HIAWATHA	BLVD	39.02	12.8	6.28	**58.10**
57	13002524	STATE	ST	35.78	12.8	9.50	**58.08**
58	13002525	STATE	ST	35.78	12.8	9.50	**58.08**
59	13011164	ERIE	BLVD	35.78	12.8	9.50	**58.08**
60	13017762	GENESEE	ST	35.78	12.8	9.50	**58.08**
61	13017763	GENESEE	ST	35.78	12.8	9.50	**58.08**
62	13028396	JAMES	ST	35.78	12.8	9.50	**58.08**
63	13028397	JAMES	ST	35.78	12.8	9.50	**58.08**
64	12573466	ERIE	BLVD	42.65	8	6.28	**56.93**
65	12578229	ERIE	BLVD	42.65	8	6.28	**56.93**
66	12578236	ERIE	BLVD	42.65	8	6.28	**56.93**
67	12578252	ERIE	BLVD	42.65	8	6.28	**56.93**
68	12578255	ERIE	BLVD	42.65	8	6.28	**56.93**
69	12578259	ERIE	BLVD	42.65	8	6.28	**56.93**
70	12578302	ERIE	BLVD	42.65	8	6.28	**56.93**
71	12578303	ERIE	BLVD	42.65	8	6.28	**56.93**
72	12578311	ERIE	BLVD	42.65	8	6.28	**56.93**
73	12578312	ERIE	BLVD	42.65	8	6.28	**56.93**
74	12578910	GENESEE	ST	42.65	8	6.28	**56.93**
75	12578912	GENESEE	ST	42.65	8	6.28	**56.93**
76	12578917	GENESEE	ST	42.65	8	6.28	**56.93**
77	12578924	GENESEE	ST	42.65	8	6.28	**56.93**
78	12579385	GENESEE	ST	42.65	8	6.28	**56.93**
79	12579403	GENESEE	ST	42.65	8	6.28	**56.93**
80	12581243	JAMES	ST	42.65	8	6.28	**56.93**
81	12581245	JAMES	ST	42.65	8	6.28	**56.93**
82	12581247	JAMES	ST	42.65	8	6.28	**56.93**
83	12581252	JAMES	ST	42.65	8	6.28	**56.93**
84	13001421	JAMES	ST	42.65	8	6.28	**56.93**
85	13001973	GENESEE	ST	42.65	8	6.28	**56.93**
86	12577881	ERIE	BLVD	45.62	4.8	6.28	**56.70**
87	12578348	TEALL	AVE	45.62	4.8	6.28	**56.70**
88	12576788	BRIGHTON	AVE	32.81	12.8	10.99	**56.59**
89	12578827	ERIE	BLVD	32.81	12.8	10.99	**56.59**
90	12578831	ERIE	BLVD	32.81	12.8	10.99	**56.59**
91	13001961	MEADOWBROOK	DR	39.02	8	9.50	**56.53**
92	13028217	MEADOWBROOK	DR	39.02	8	9.50	**56.53**
93	12575068	BEAR	ST	39.02	12.8	4.30	**56.13**
94	12581012	GRANT	BLVD	39.02	12.8	4.30	**56.13**
95	13018693	GRANT	BLVD	39.02	12.8	4.30	**56.13**
96	13020698	ONONDAGA	ST	39.02	12.8	4.30	**56.13**
97	13022412	ONONDAGA	ST	39.02	12.8	4.30	**56.13**
98	13028444	ONONDAGA	ST	39.02	12.8	4.30	**56.13**
99	12577749	HARRISON	ST	36.05	12.8	6.28	**55.13**
100	12577761	HARRISON	ST	36.05	12.8	6.28	**55.13**

References

AASHTO. (1985). *Guidelines on Pavement Management*. Washington, DC: American Association of State Highway and Transportation Officials.

Acharya, D. (2014). Transportation Asset Valuation. Retrived from ProQuest. Dissertation/Thesis Number: 1601054.

Assaly A.E., Ho, P., & Kwan, A. (2005). Proceedings from Annual Conference of the Transportation Association of Canada: *Development of Decision Support System for Highway Capital Planning in Alberta, Canada.* Calgary, Canada.

Bham, N. G., & Darter, M. I. (2001). Proceedings from Twenty First ESRI User Conference: *Development of GIS-based Illinois Highway Pavement Management System*. San Diego, CA.

City of Syracuse. (2011). *Chapter 1: Current Conditions*. Syracuse, NY. Retrieved from http://www.syracuse.ny.us/uploadedFiles/Departments/Planning_and_Sustainability/Content/Chapter%201%20-%20revised.pdf.

City of Syracuse. (2016). [Map of flooding zones in the City of Syracuse]. *City of Syracuse Special Flood Hazard Area*. Retrieved from http://www.syrgov.net/uploadedFiles/Departments/Engineering/Content/2016%20SFHA%20for%20MO%20072516.pdf.

Dalal, J., Mohapatra, P. K., & Mitra, G. C. (2010). Prioritization of Rural Roads: AHP in Group Decision. *Engineering, Construction and Architectural Management*, 17(2), 135-158.

Fakhri, M., & Dezfoulian, R. S. (2017). Application of GIS for Pavement Maintenance Prioritization Based on a New Approach at a Network Level. *Journal of Engineering Technology*, 4(2), 24-30.

FEMA. (2015). *Critical Facilities and Higher Standards*. Washington, DC: Federal Emergency Management Agency.

FHWA. (1992). *Safety Effectiveness of Highway Design Features. Volume 1: Access control.* Washington, DC: Cirillo, J. A.

FHWA. (2003). *Distress Identification Manual for the Long-Term Pavement Performance Program*. Publication # FHWA-RD-03-031.

FHWA. (2017*). AASHTO Transportation Asset Management Guide*. Washington, DC: Federal Highway Administration

FHWA. (2017). *Bases and Subbases for Concrete Pavements*. Publication # FHWA-HIF-16-005.

FHWA. (2017*). FHWA Functional Classification Concepts, Criteria, and Procedures*. Washington, DC: Federal Highway Administration.

FHWA. (2017). *Flexibility in Highway Design*. Washington, DC: Federal Highway Administration.

Goose, C. A., Smith, B. L., Clarens, A. F. (2013). Environmentally Preferable Pavement Management Systems. *Journal of Infrastructure Systems*, 19(3), 315-325.

Gupta, A., Kumar, P., & Rastogi, R. (2011). Pavement Deterioration and Maintenance Model for Low Volume Roads. *International Journal of Pavement Research and Technology,* 4(4), 195-202.

Haas, R., Hudson, W. R., & Zaniewski, J. (1994). Modern Pavement Management. Malabar, FL: Krieger.

Hendrickson, C. T., Lave, L. B., & Matthews, H. S. (2006). Environmental Life Cycle Assessment of Goods and Services: An Input-Output Approach. New York, NY: Routledge.

Horvath, A., & Hendrickson, C. (1998). Steel versus Steel-Reinforced Concrete Bridges: Environmental Assessment. *Journal of Infrastructure Systems*, 111-117.

Kruntcheva, M. R., Collop, A. C., & Thom, N. H. (2005). Effect of Bond Condition on Flexible Pavement Performance. *Journal of Transportation Engineering*, 131(11), 880-888.

Maeda, K., Takahashi, S., Ogawa, T., & Haseyama, M. (2017). Distress Classification of Road Structures via Adaptive Bayesian Network Model Selection. *Journal of Computing in Civil Engineering*, 31(5).

Meleki, K. H. (2009). Development of an Asset Management Implementation Reference Model and Effective Change Management Strategies for Transportation Agencies. Retrived from ProQuest. Dissertation/Thesis Number: MR80713.

NYS Department of Transportation. (2016). [Map of Average Daily Traffic Amounts in Syracuse, NY]. *NYS Traffic Data Viewer*. Retrieved from https://gis3.dot.ny.gov/html5viewer/?viewer=tdv.

Onondaga County. (2010). Major Employers [Data File]. Retrieved from http://www.ongov.net/about/majorEmployers.html

Pietrzycki, J. (2014). Analytical Hierarchy Process in Pavement Management Systems. Retrived from ProQuest. UMI Number: 1587470

Pirzadeh, S. (2008). A Critical Review of Existing Literature on Life Cycle Assessment of Pavements and Bridges. Retrieved from ProQuest. UMI 1537478.

Pratap, D., Vemula, K. K., Prasad, C. S., & Reddy, S. P. (2006). Proceedings from Map India Conference, GIS Development: *Highway Information System and Management Using GIS*. New Delhi, India.

Robinson, R., Danielson, U., & Snaith, M. (1998). Road Maintenance Management. New York, NY: Palgrave.

Rouphail, N. M. (1985). Minimum-Cost Design of Flexible Pavements. *Journal of Transportation Engineering*, 111(3), 196-207.

Saaty, L. T. (2008). Decision Making with the Analytic Hierarchy Process. *International Journal of Services Sciences*, 1(1), 83-97.

Salem, O. S. (2014). *Assessing the Environmental Impacts of Work Zones in Arterial Improvement Projects*. TranLive Report. Retrieved from http://tranliveutc.org

Santero, N, Masanet, E., & Horvath, A. (2010). *Life Cycle Assessment of Pavements: A Critical Review of Existing Literature and Research*. . Skokie, Illinois: Portland Cement Association. Report # SN3119a.

Shahin, M. Y., & Kohn, S. D. (1979). Development of Pavement Condition Rating Procedures for Roads, Streets and Parking Lots. Champaign, IL: Army Construction Engineering Research Laboratory.

Shahin, M. Y. (2005). Pavement Management for Airports, Roads, and Parking Lots. New York: Chapman and Hall.

Shrestha, P. P., & Pradhananga, N. (2009). GIS-Based Road Maintenance Management. *Computing in Civil Engineering*. Retrieved from http://ascelibrary.org

Stripple, H. (2001*). Life Cycle Assessment of Road: A Pilot Study for Inventory Analysis*. Gotherburg, Sweden: IVL Swedish Environmental Research Institute.

Sun, L., & Gu, W. (2011). Pavement Condition Assessment Using Fuzzy Logic Theory and Analytic Hierarchy Process. *Journal of Transportation Engineering*, 137(9), 648-655.

US Census Bureau. (2016). Population of Syracuse [Data File]. Retrieved from https://www.census.gov/quickfacts/fact/table/syracusecitynewyork#viewtop.

Vita

Kirill Skorokhod

EDUCATION:

Syracuse University

College of Engineering and Computer Science

Master of Science, May 2018

Major: Civil Engineering, Construction Management

Syracuse University

College of Engineering and Computer Science

Bachelor of Science, May 2016

Major: Civil Engineering

ACADEMIC WORK EXPERIENCE:

Graduate Teaching Assistant

Department of Civil and Environmental Engineering, Syracuse University

August 2016 – January 2017

- Leading and developing recitation lectures related to the Transportation Engineering, Engineering Materials and Construction Managements courses
- Conducting personal thesis research as well as the research for the Department of Civil Engineering
- Assisting a professor during lectures by collecting homework and answering student questions relevant to the material of the courses
- Grading homework assignments and exams as well as holding office hours to help students in preparing for exams, solving homework problems and utilizing engineering software