PLACEMENT OF UTILITIES IN RIGHT OF WAY MODEL USING FUZZY AND
PROBABILISTIC OBJECTIVE COEFFICIENTS

by

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This thesis focuses on a decision-making model for finding the locations for placement of utilities in roadway corridors. In recent years, there has been a rapid growth in the volume of traffic on roadways and in the number of utilities placed in Right of Ways. The increase in the demand for utilities is making it more difficult to place all the utilities within the Right of Way and also provide safe roads and highways with good carrying capacity. The public agencies approving the location for utilities are now using a first come first served method, which provide neither an efficient nor good economic solution. This model considers all the utilities within the corridor as a single system, including factors like installation costs, maintenance costs and also some future factors such as accident costs. A weighted coefficient optimization approach is used to find the solution in this model. These costs are modeled as fuzzy numbers or probabilistic random numbers depending on their characteristics. This algorithm will locate each utility at all its possible locations and find the total cost of all the utilities at all these locations, i.e. cost of the system. The least cost locations among all
the possible locations are the good locations for utilities in the utility system. When utilities are placed in these locations the overall cost of the system will be lower compared to other locations. This model provides a flexible and interactive method for finding cost saving locations for the utilities in the highway corridor. Users will be able to change the parameters of the utility system according to their requirements and get reduced cost solutions.
1. INTRODUCTION

Roads and Highways are the backbone of the transportation system. They have become an essential part in our day-to-day lives. Other than transportation, roads and highways serve the important role of accommodating utilities in their Right of Way (ROW). “A utility is defined as a privately, publicly or cooperatively owned line, facility or system for producing, transmitting, or distributing communications, cable television, power, electricity, light, heat, gas, oil, crude products, water, steam, waste, storm water not connected with highway drainage or any other similar commodity including any fire or police signal system or street lighting system, which directly or indirectly serves the public” (1).

Utility firms provide to the public necessary basic services such as water, sewer, telephone, gas, electric, cable TV, etc. Utility lines can either be underground (like water or sewer lines) or above the ground aerial structures (like electric or telephone lines). Utility firms install their lines and facilities on the ROW of the public roads and streets. “Right of Way is defined as any part or access to a public agency’s transportation facility above, at the surface or below the ground” (2).

This concept of utility-transportation corridor has been used since 1916 in United States of America (3). ROW offers the most practical engineering, construction and maintenance solutions for utility service to business and residences (1). A ROW provides the necessary space for the utility distribution
and access. Many times property owners would not willingly allow utility facilities to cross their land, and access to adjacent properties would be blocked. This is another reason for the joint ROW use.

If the utilities were not allowed to use the ROW, they would be required to purchase their own land, driving up the overall cost to the utility organization. This increase in cost to the utility companies will increase the cost for the public.

For these reasons, it is generally considered in the best interest of the public to allow joint use of ROW when it does not impair surface use of roads and highways by the public. Each utility is given some consideration of ROW space and privileges. But the use of ROW by them is subject to the approval and overall control of a public agency.

For example, State Departments of Transportation (DOT) are public agencies that have authority over the ROW. The functions of these agencies start with the acquisitions of lands for the ROW and the highways. They also have other responsibilities like operating the roads and streets in a way that ensures the safety, traffic-carrying ability and physical integrity of their facilities. A utility’s presence within the ROW can affect these characteristics, so it is necessary for these public highway agencies to regulate the utility’s presence.

Utility firms are governed by regulatory rules for placing their utility lines and facilities in the highway’s ROW. The governing public agencies frame these regulatory rules for the utilities. Whenever a utility company gets an approval for placing their lines, these rules should be strictly followed for placing their utilities.
In addition to these laws, rules and regulations, professional organizations and their publications influence utilities’ rights and rules within the ROW. Some of them are:

1. American Association of State Highway and Transportation Officials organization (AASHTO) has prepared policies and guides to distinguish good highway/utility practices.

2. Federal Highway Administration has released a program guide for utility relocation, adjustments and accommodation on federal-aid highway projects.

Many of the present Roads have narrow ROW or they are in crowded urban areas. There is a tremendous growth in traffic in recent years. At the same time, the public has created a demand for increased access to various utilities. It has become very difficult to upgrade these older roads to provide the necessary capacity and safety for motorists, while trying to place more and more facilities on the same crowded ROW.

Recently, due to rapid growth of customers for companies like telecommunication, cable TV and Internet providers, there is a huge increase in the number of utilities that distribute these services to the public. On considering the present number of utilities and forecasting possible new utilities, a wide range of utilities have to share the ROW. However, ROW space available at present is very limited and will be crowded with these increasing numbers of utilities. The increase in the number of utilities has also greatly increased demand for access to the ROW.
This crowding may cause many serious concerns like damage to the infrastructure, public safety and interruption of services to the customers, especially while installing or repairing utilities in the congested utility corridor, there are chances for causing damage by interring the existing utilities in the corridor. This damage may cause an interruption of services to the customers, which is not desirable. Also, this may cause safety concerns if damage is made to gas or other sensitive utilities. There are also many chances for disruption to traffic flow and damage to the roads. These are some of the common problems encountered due to the congestion in the utility corridor. There are also concerns about utility poles and other above ground structures. Road accidents are prime concerns in the case of aerial utility poles.

The demand for good road and highway systems for increasingly sophisticated utility service will continue to grow very fast. There may be many occasions where two or more utility companies will desire to occupy a common space within the ROW. The construction of new facilities and maintenance of the existing facilities will continue to cause problems that must be solved. These concerns and problems led to research of a number of issues like congestion, compatibility, associated liability, relocations, safety factors and costs associated with engineering, construction, maintenance, and relocation of these utilities.

1.1. Research Problem Overview

This research presents a decision-making model that will help to build a better utility system. The decision-making model helps to find good locations for placement of the utilities in the ROW of roads and highways. The method
currently followed by the public agencies for approving the location for the utilities is not an efficient method because of disadvantages such as total cost of the system not considered and not following any engineering principles. The model in this research is better because it can be used for finding the location for placing the utilities and it resolves many problems with the present method. This model uses optimization principles to model the system and to find the solution, while the present method is a simple first come first served method governed by rules and regulations of the public agencies maintaining the ROW of the roads and highways.

This model finds the location for the utilities for a new highway construction in which all the utilities are laid new. The model takes into account all the characteristics as necessary for the users such as safety concerns, relocation, clearance, etc. The location of the utilities depends on factors that are typically modeled as cost factors. In this research, the cost factors include the present cost and future cost that can be incurred by the utilities. In addition, other factors such as accidents and increase in demand are taken into consideration by this decision-making. Each cost factor is modeled according to its characteristics. This model also handles the uncertainties in some of the cost factors by using fuzzy sets.

1.2. Thesis Outline

This thesis is organized as follows: Chapter 2 discusses the literature review of solution techniques used in this research like fuzzy sets and weighted coefficients optimization. In Chapter 3, the problem of this research is discussed
in more detail. Chapter 3 also explains the utility system and its characteristics.

In Chapter 4, the methodology that is used to model the decision-making model in this research is discussed using a sample utility system. The results of this research are discussed in Chapter 5. Chapter 6 gives the conclusion for this thesis and also discusses some of the limitations in this research. Finally, in Chapter 7 possible extensions of this research are discussed.
2. LITERATURE REVIEW

In this chapter, the literature review about the placement of utilities in the roads and highways is discussed. This chapter also discusses fuzzy sets and weighted coefficient optimization techniques.

2.1 Utility Corridor

Utilities are located in the ROW of the transportation roads and highways. Public utilities have located transmission lines in the federal highway ROW as early as 1916 (3). In 1956 when the national system of interstate highway program was created, it became apparent that control of access was essential to maximize safety and to preserve the traffic carrying capacity of the highway system (1).

The American Association of State Highway and Transportation Officials organization (AASHTO) prepared “The Policy on the Accommodation of Utilities on the National System of Interstate and Defense Highways” in 1959. In 1966 all state departments of transportation in-charge of their state’s highways followed these regulations given by AASHTO. The Federal government required each state to develop and maintain a Utility Accommodation Manual (UAM) to summarize policies regarding location and relocation of facilities within each corridor.

Since then, there has been a rapid growth in traffic volume, vehicle speed and vehicle weights. The network of roads and highways has grown vaster over the
years. Along with the highway system, the need for the public utilities grew more and more resulting in much bigger distribution systems i.e. utility systems. New growth and expansion of utility systems have resulted in increased demand and increased competition for the space available on highway ROW for public utilities. Due to this increase in demand for space there are more problems and concerns like damages to infrastructure, safety concerns, traffic disruptions, etc. that require a better solution than provided in the accommodation manuals, which are based on rules and regulations.

A number of research projects have been done in this area and many suggestions have been given to solve some of the problems in this area. Some of them are discussed below.

2.1.1. Common Trenching

Common trenching is a cost effective method for installing multiple utilities. In common trenching two or more utility companies will dig at one location and place their facilities in a common trench. Commonwealth Edison and Illinois Bell used this technique as early as 1960 in the United States. This technique will eliminate the congestion of utilities within the ROW. But there are some issues like space between the utilities within the trench. Another main problem is the safety issue due to the close placement of utilities there are possibilities of interference between the utilities especially like electric, gas, and communication lines. There are also chances for contamination of potable water with sewage (4).
2.1.2. Utility Corridor

A utility corridor is another possible solution, which is under research and in use in a small scale in private corporations such as on Walt Disney land. “A corridor is defined as a passageway with compartments or rooms.” (4). Utility corridors are structures made of metal or concrete designed according to the requirements. But special attentions are needed for ventilation, lighting, spacing, maintenance, etc.

Some researchers believe that better cooperation and coordination between utilities and public agencies at all levels can improve the situation. A well-organized, representative coordination group is the best mechanism for improving interrelated utility-transportation coordination groups (7, 8).

2.1.3. One Call Service

Another service introduced by the governmental agencies to prevent accidents and damage to utilities while evacuation is “One Call Service”. One call service functions as a process to communicate the intentions of an excavator to dig in a particular area. These intentions are then communicated to a one call center that notifies all companies that have facilities in that particular area (6).

2.1.4. Trench-less Technology

Trench-less technology has been described as the collection of technologies and methods that can be used to repair, upgrade, replace or install underground infrastructure systems with minimum surface disruptions (13). The development of trench-less methods has been due to the increasing amount of underground infrastructure that is under capacity for today’s society. This
technology is used successfully by most of the utility companies today. It helps to keep the surface disruptions to a minimum, thus considerably reducing the cost (12, 13).

2.1.5. Subsurface Utility Engineering

“Subsurface Utility Engineering” (SUE) is the solution for the inability to obtain reliable underground utility information. “Subsurface Utility Engineering is an engineering process that incorporates new and existing technologies to accurately locate underground utilities, during the early development of a highway project” (9). It involves designating, locating and data management of the information collected. SUE is considered a fast growing technology of the future. It gives information that helps all the people in this field to a great extent. Subsurface Utility Engineering,

1. helps highway projects by elimination of unexpected conflicts with underground utilities during construction,

2. avoids relocation of utilities, and

3. prevents accidents and damages to utilities.

This practice of Subsurface Utility Engineering that gives more accurate information about the actual location of underground utilities is gaining more and more importance. But the process of collecting and managing all the information is very difficult and it involves a lot of resources. This is a very costly technique at this time (10, 11).
2.2 Fuzzy Sets

In 1965 Zadeh first proposed fuzzy set theory (17). Since then it has rapidly developed and has been successfully applied in many areas like expert systems, industrial controllers, washing machines, etc. Bellman and Zadeh were the first to use fuzzy set theory in the field of decision-making (14). Since then a lot of research has been done in the area of fuzzy linear programming, fuzzy multi objective programming, fuzzy goal programming etc.

In contrast to the crisp set, a fuzzy set does not have a clear boundary. Consider a fuzzy set $A$ which is a subset of universal set $X$. Fuzzy set theory defines the degree to which element $x$ of set $X$ is included in the fuzzy set $A$. It means that in fuzzy set partial membership is allowed. The function that gives the degree to which a member is included in a fuzzy set is called the membership function. The membership function generally takes a value in the range from 0 to 1. 0 represents null membership, 1 represents full membership and in-between values represent partial membership.

For example, consider the case of temperature in which cold temperature will be a fuzzy set. In classical set theory all of the temperatures that are below $70^\circ$ are considered cold temperatures while all that are above $70^\circ$ are not considered cold temperatures as shown in Figure 1. But in the case of fuzzy set theory, there is a partial membership that allows temperature to have a membership according to the closeness to the set. $60^\circ F$ may have a membership function of 0.8 in the cold set of temperatures while $71^\circ F$ may have a membership of 0.3 in the cold set of temperatures as shown in Figure 2. There
NOTE: ALL VALUES ARE IN GENERIC UNITS

Figure 1: Classical Set Theory

NOTE: ALL VALUES ARE IN GENERIC UNITS

Figure 2: Fuzzy Set Theory
are many diverse applications for which it is impossible to get relevant, accurate data. For example, it may not be possible to measure essential parameters of a process such as temperature inside a molten glass or the homogeneity of a mixture inside a tank (15). Unclear information or parameters of the system creates fuzziness of the information of the system. Fuzzy set theory can overcome this fuzziness in the information due to incomplete or inaccurate data. In this research, the fuzzy sets are used to model some of the cost coefficients. Many data on the costs of the utilities are not accurate and incomplete. Fuzzy sets can help to overcome this incompleteness in the cost coefficients. If the incomplete data are used, then the solution for this problem may not be accurate. Fuzzy set theory helps the model achieve more accurate solutions to problems.

2.3. Fuzzy Optimization

Fuzzy optimization is the same as the optimization with the addition of fuzzy coefficients or constraints. In this research, fuzzy sets are used for modeling cost coefficients of the objective function. The model combines the advantage of the fuzzy sets and optimization. Bellman and Zadeh (14) introduced an approach for the application of fuzzy set theory to decision-making under uncertainty. In this approach the objective function and some or all constraints are represented by fuzzy sets. Many researchers have proposed different methods for applying fuzzy set theory in mathematical programming.

Zimmermann (16) modeled the objective function and the constraints as fuzzy sets. By modeling the strict requirements of the objective function and constraints by fuzzy sets he fuzzified them and developed a fuzzy mathematical
model. Zimmermann used the combination of linear membership and minimum operation to transform fuzzy model into an equivalent linear programming model. Zimmermann was first to present an approach to solve a fuzzy linear programming problem. He assigned a piece-wise linear membership approach to every objective function in this model. The piecewise linear membership functions of these objectives transformed the fuzzy linear programming problem into linear programming. The solution of this linear programming problem was considered as compromise solution of the fuzzy optimization problem.

In 1987, Werner fuzzified a crisp objective function by solving two linear programming models (18). One linear programming model employed lower bound and the other used upper bound. He also presented fuzzy and aggregating operators, which with linear membership functions transformed the fuzzy model into a 0-1 integer-programming model. Other significant contributors are Tanaka and Asai in 1986, who modified Zimmermann’s approach by modeling coefficients and constraints as fuzzy numbers (20). Also, Negotia and Sularia formulated fuzzy linear programming problem using fuzzy numbers in objective functions and constraints (21). The sample principle is used in this research, in which some parts of the objective function are modeled as fuzzy numbers that will help to reduce the uncertainties in those objective functions.

2.4. Weighted Coefficient Optimization

In this research, fuzzy optimization problem is solved by the weighted coefficient approach. This approach has been used quite extensively especially in decision-making, where the weights are used to represent the relative
importance that the decision maker attaches to different decision criteria (19). This method takes each factor and multiplies it by a fraction of one, the "weighting coefficient" which is represented by $w_i$. The difference in the preference for the factors is represented by a set of weight factors $w_i$. The modified functions are then added together to obtain a single cost function, which can easily be solved using any single-objective method. Mathematically, the new function is written as:

$$ F(x) = \sum w_i f_i(x) $$

Where:

$0<w_i<1$ and

$$ \sum w_i = 1 $$

$f_i(x)$ is objective function of each factor

$w_i$ is weight for objective function of each factor

$i = 1, 2, 3, \ldots$
3. PROBLEM STATEMENT

“Utilities are an integral and essential part of our national infrastructure” (5). These utilities perform the important function of providing the basic essentials such as water, sewer, telephone, cable TV, and natural gas. As discussed in the previous chapters, delivery of these services to the public is done by a large distribution system, located within the ROW of the highways and roads. ROW of the highways and roads are under the control of public agencies like state Departments of Transportation. These public agencies have to approve a space for the utility companies to place their lines or facilities within the ROW of the highways.

Most of these public agencies follow first come-first served procedure for approving the spaces for the utility lines. This procedure is explained in Figure 3. These are the steps followed by the public agencies for approving a location for a utility according to Florida Department of Transportation’s Utility Accommodation Manual (2). The same steps will be repeated for the next utility company, but the only difference is the previous space allocated will not be available this time. Most of the time companies coming early will get desired spaces for locating their utilities. So these desired spaces will be the best available space at that time for that utility. So in this method, the chances of getting better space/location depend on the time of arrival.
Available space for utilities is given by public agency

Utility firm finds the best available location for its facilities

Utility firms apply for the chosen location to the public agency

Public agency checks the chosen location for maximum safety

No

Utility firms choose another location

Public agency checks the same location for rules and regulations of the accommodation manual

Yes

Location approved for that utility

Figure 3: Current Method of Approval for Utility Location
A location is said to be good if the overall cost factor for placing the utility at that location would be least. This cost factor depends on these following factors:

1. Installation cost.
2. Access or maintenance cost.
3. Risks of accident.
4. Danger to public.
5. Chances for disturbing traffic.
6. Chances for relocation.
7. Chances for damaging other utilities.

This first come-first served method is very simple and easy to follow. In this method, utility firms coming early have a better chance of getting a good location than the ones coming later. Some of the problems with this method are:

1. It is advantageous to only some of the many companies.
2. It is not based on any engineering principle.
3. Each utility is considered separately.
4. The total cost of the utility system is not considered.

Other than these, many individual agencies and companies plan improvements to their facilities without considering other facilities, which may directly affect or be affected by these plans (1). All the utilities in the ROW should have the same opportunity for placing their facilities in the ROW. All private and public utilities including communication, electric power, water, gas, oil, petroleum products, steam, sewer, drainage and irrigation and similar facilities affecting the public ROW should be given similar attention for
accommodation. All activities of these facilities including placement of new facilities, extension of existing service lines, replacement/upgrading of existing facilities, maintenance and service connection has to be considered while taking steps to solve the existing problems. There should also be anticipation and preparation for future events.

This research gives a decision-making model for the placement of utilities in the ROW. In this research, the model was developed for a new construction facility in which all the utilities are newly laid. The model incorporates all the characteristics of the utilities and also follows the rules and regulations of the public agencies. This model considers the whole utility system as a single system, during which each utility within the ROW is considered as an entity of the system. Instead of finding the solution for each entity like the previous methods, this model minimizes the total cost of the whole system that include costs of all the entities. In this model, each utility may not get the best location for placing their facilities but on a whole the utility system will have better locations compared to the previous methods followed. So, the total cost of the utility system is minimized, which apparently reduces the total cost for utilities to the public. The expected end result of this model is the best allocation of the resources i.e. space in the ROW so that the cost of the utility system is minimum.

3.1. System Description

The relevant description of the utility system is summarized in the points below:
1. All the utility systems and corridors considered in this research are for new construction.

2. The system is made up of many utility facilities like water, sewer, communications, cable television, power, electricity, light, heat, gas, oil, crude products, steam, waste, storm water, etc.

3. All these utilities are accommodated within the ROW of the highway system.

4. This ROW area available for placing the utilities will vary from small streets to Interstate highways.

5. In some cases utilities are located below the pavement or the sidewalk of the roads.

6. All the utilities that are placed within the ROW are located according to the guidelines of the public agencies.

7. Each utility line or facility will have its own characteristics like size, shape, constraints, etc.

8. There can be more than one utility line of a same utility type. For example, there can be two telephone lines with the ROW belonging to same or different utility firms.

9. Aerial structures should not be located within the area in the ROW called clear zone to prevent accidents to the vehicles." Clear Zone is defined as the recovery area that should be free of obstacles such as unyielding sign and luminarie supports, non-traversable drainage structures, utility poles and steep slopes" (2).
There are several factors, which will affect the placement location of the utilities. All these factors are considered as cost factors and given a cost. All of these factors depend on the location of the utility. These factors for each utility will vary depending on the type of the utility and the location where it is placed. All these factors are considered as cost factors. Some of these cost factors are present costs and some of them are future costs. The cost factors are discussed below.

1. Installation costs

These are the costs that are incurred before and during the installation process for a utility. Some of the costs that are included in the installation costs are digging cost, burying cost, etc.

2. Access costs

These costs are the costs that are incurred for providing access to the new customers. These are future costs, which are incurred over a period of time after placing the utility.

3. Maintenance costs

Costs that are incurred at a regular interval for the periodic maintenance of the utility are called maintenance costs. These costs are future costs that are predicted for regular periods of time.

4. Accident costs

These are costs that are incurred due to unexpected accidents. Accidents can be due to installation of other utilities, road repair, natural causes, road
accidents or any other reason like this. These are also future costs but they are not predicted costs.

5. Damage prevention costs

These are costs that are spent before any damage is resulted to the utility. This can be the cost spent to locate the utility, for participation in one call, money spent for educating the representatives, etc. (5).

6. Replacement costs

The cost required for replacing the utility when its lifetime is over. This is a planned cost that is expected after a period of time.

7. Relocation costs

These are costs that are incurred for moving a line to another location within the ROW. There are future cost and most of the time they are not expected. They also include the cost of moving aerial structures to underground lines (5).

8. Burden on public agencies

The costs associated with permitting, ROW acquisition and other administrative functions relative to the utility system, etc. that come under the public agencies.

9. Other factors

Other factors such as environmental issues, maintaining the vegetation above the utility corridor, bridges, rail crossings, etc should also be considered while finding the best location for utilities.
4. METHODOLOGY

The methodology for developing the heuristic decision-making model for finding good locations for placing the utilities in a new facility to reduce the cost of the utility system is discussed in this chapter.

4.1. Sample Utility System

A small-scale sample of a utility system is considered for modeling the decision-making model is used to show how the model works. This sample utility system has the characteristics of a typical utility system. The characteristics and assumptions of the sample utility system are given below:

1. This utility system is for a new highway or road.

2. The system only considers straight-line placement and does not consider turns or crossings in the ROW.

3. There are six utilities (entities) in this utility system. They are:
   1. An electric line
   2. A water line
   3. A sewer line
   4. Two telephone lines
   5. A natural gas line

4. The available space for placing the utilities is 6 feet in width. (In those six feet, one foot is under the pavement and one foot is under the sidewalk).
5. The following are the constraints to be followed by the utility firms for placing their utilities in the given ROW area.

1. Clearance

   Clearance is the space around each utility, which should not be used by any other utility. Clearance of two utilities can intersect but one utility cannot be placed in any other utility’s clearance area.

2. Minimum cover (Depth)

   Minimum cover is the minimum distance below, which each utility has to be placed.

3. Maximum depth

   Maximum depth is the maximum allowed depth for placing a utility.

   Very deep placement of utilities may be affected by water table or high pressure on the utility lines.

4. Stacking

   Stacking means placing one utility above or below another utility.

   Some utilities allow placement of other utilities under them but some of the utilities restrict this type of locating.

5. Below sidewalk

   Below sidewalk is the constraint of placing utilities under the sidewalk.

   Some types of utilities have restrictions for this.

6. Below pavement

   Below pavement is the constraint of placing utilities under the pavement. Some types of utilities have restrictions for this also.
7. Separation between water and sewer lines

There should be a minimum distance (both vertical and horizontal) between the water and the sewer utility lines. This constraint ensures this clearance between water and sewer.

All of the six utilities have different characteristics and constraints. Figure 4 shows the characteristics of the utilities.

Figure 4: Characteristics of the Utilities
4.2. Decision-Making Model

The decision-making model finds the locations for the utilities so that the cost of the utility system is minimum. In this model, all the utilities in the system are considered as entities of a single system. So the optimization is done for the whole utility system and not done for each utility separately. There are many factors such as installation costs, maintenance costs that affect placement of the utilities, so these factors have to be considered for finding the solution.

In this model, three factors considered for modeling are installation costs, maintenance costs and accident costs. The sum of these three objective functions gives the overall objective function. The decision-making model minimizes the overall objective function. The mathematical representation of the final objective function is given as:

\[
\text{Min } F(X)
\]

\[
F(X) = F_I(X) + F_M(X) + F_A(X)
\]

Where:

\[
F_I(X) = \sum_{j=1, \ldots, 6} f_{Ij}(x)
\]

\[
f_{Ij}(x) \text{ is installation cost objective function of utility } j
\]

\[
F_M(X) = \sum_{j=1, \ldots, 6} f_{Mj}(x)
\]

\[
f_{Mj}(x) \text{ is maintenance cost objective function of utility } j
\]

\[
F_A(X) = \sum_{j=1, \ldots, 6} f_{Aj}(x)
\]

\[
f_{Aj}(x) \text{ is accident cost objective function of utility } j
\]
Each factor influencing the optimization can have different levels of priorities on the solution. The “Weighted Coefficient” approach helps to give different level of priorities to each factor for finding the solution. In this technique, each factor/objective function is given a weight coefficient according to its level of importance in determining the solution. This helps the user to set the priorities according to the requirements. The corresponding weight coefficient is multiplied with its objective function when finding the overall objective function.

The mathematical representation of the total “weighted coefficient” multi-objective function is:

\[
\text{Min } F(X) = w_1 F_I(x) + w_2 F_M(x) + w_3 F_A(x)
\]

Where:

\(F_I(x)\) is installation cost objective function
\(F_M(x)\) is maintenance cost objective function
\(F_A(x)\) is accident cost objective function
\(w_1\) is weight for installation cost objective function
\(w_2\) is weight for maintenance cost objective function
\(w_3\) is weight for accident cost objective function

\(0 < w_i < 1\) and

\(\sum w_i = 1\) for \(i = 1, 2, 3\)
4.3. Cost Coefficients

Cost coefficients are the cost for each utility at a particular location. These are the coefficients of the objective functions. The data needed for these cost coefficients are collected from different organizations like state departments of transportation, utility construction company, utility owners, etc. All these data have to come from different sources and there is a lot of variation in these data. These data needed for the cost coefficients in the objective function cannot be used directly in the cost coefficients because they are not always accurate in some cases and in some other cases these costs are future costs so they are forecasted using the available data. So these data have to be modeled in some way so that they represent the cost of the utility at that location. The cost coefficients are modeled according to their characteristics.

4.3.1. Installation Costs

The costs that are incurred during the installation process of a utility are called installation costs. These costs vary depending on factors such as location, type of the utility, method used for installation of the utilities, etc. The sources of information about these costs are collected from different organizations. It is hard to get accurate and complete information for this cost since it depends on so many factors and varies greatly. The data available are not complete and they are inaccurate. In order to overcome the incompleteness in the data, these costs are modeled as a fuzzy numbers. Fuzzy numbers can adequately handle the incompleteness and inaccuracies in the data and they take care the incompleteness and inaccuracy in the data of the installation costs.
4.3.2. Maintenance Costs

The costs that are used for maintaining a utility over a period of time are included as maintenance costs. These costs also depend on factors like location, type of utility, etc. The data for these costs are collected from utility maintenance firms. These costs are regular costs that are incurred regularly for a period of time. For example, a water utility may incur a maintenance costs between 500 dollars to 650 dollars for a year when placed at a particular location. From the historical data, these costs are found to vary within a range. Since the ranges of these costs are known, these costs are modeled as a uniform random number, which is a random number that is generated between two limits, or a range.

4.3.3. Accident Costs

As discussed earlier, there are unpredicted future costs that are caused due to sudden failures in the utility system. The failure can be due to road repair, installation of other utilities, natural causes, road accidents, or any other reason. The costs that are incurred due to sudden accidents are called accident costs. The number of accidents can only be forecasted with data available. Similarly the extent of the accident also contributes to the accident costs. These costs can vary from a minimum value to a maximum value because both the extent of the failures and the number of failures over a period of time, which determines the accident costs, can vary greatly. The numbers of failures are modeled commonly as exponential random numbers, from any number between zero to
stated maximum. Accident costs are modeled as exponential random numbers since these costs depends directly on the number of failures.

4.4. Working of the Model

The decision-making model gives the location for placing the utilities in the utility corridors. The solution is found by taking into account the characteristics and constraints of the utility system. The utility system is simulated in the model so that all the characteristics and constraints are accommodated.

First, the available space for placing the utilities with the ROW is divided into equal areas or grids. Each grid was divided into spaces of 0.5 ft size. The grids are represented by the matrix $S$. $S$ is a two dimensional matrix with $h$ number of grid elements in rows and $v$ number of grid elements in columns. In the utility system considered, a possible space available for locating the utilities is 6 ft. wide of which 1 ft. is under the pavement and 1 ft. is under the sidewalk. In addition to the 6 ft. of available space, clearance space of 1 ft. is considered in all four directions for the $S$ grid matrix. A vertical height for the available space is considered to be 5 ft., which ranges from 2 ft. to 6 ft. Thus, $S$ is a [16, 10] matrix as shown in the Figure 5.

Each grid element has a value depending upon the placement of the utilities as shown if Figure 5, the values within each boxes. When a utility is placed at a location all the grid elements that are part of that location are considered to be occupied by the utility and all these grid elements are assigned a value of 1.5. The number of grid elements occupied by each utility depends on the size of the utility. Similarly all the grid elements in the clearance area of
Figure 5: Grid Matrix Showing Values in Each Grid According to the Utilities’ Locations.

each utility along with the grids in the utility location are assigned a value of 0.5.

Dividing the available space into grids helps maintain the concept of one utility at
a location and also for maintaining the clearance area of the utilities. So all the grid elements are checked for their total value and if it exceeds 2 then there is a violation of the either placing one utility at a location or placing a utility in a clearance area of another utility. In Figure 5, the grid elements with a value of 2 have a utility located in their area.

Stacking is accommodated in the model in a similar way. Stacking is considered like a clearance for that utility and all the grid elements lying in the column of the utility placed grids are given a value of 0.5. This ensures the stacking and no other utility can be placed in those locations. The distance between water and sewer is modeled by checking whether the difference between the horizontal locations and vertical locations are more than the required distance of separation between the two utilities and whenever this is true then that solution is eliminated.

For each utility the number of possible locations is found. The number of possible locations is calculated by following the constraints minimum cover, maximum depth, if under pavement not allowed and under sidewalk is not allowed. For example, there are 11 X 5 possible locations for the water utility as shown in Figure 6. Similarly, possible locations for all the other utilities are found. This model places each utility at all possible locations and finds the cost of the system. The location of the utilities at which the total cost of the system is the minimum is considered to be the final solution of the problem. The model is run several times and the most occurring solution is found. This solution then gives a good location for placing the utilities in the utility corridor.
4.4.1. Modeling with Fuzzy Numbers

The cost coefficients of the objective function installation costs are modeled as fuzzy numbers, which help to overcome the incompleteness and inaccuracies in the data of the installation costs. They are modeled using the Fuzzy Logic toolbox in Matlab software. For each utility, a cost matrix of fuzzy numbers is developed which are the cost coefficients of the installation costs.
The installation costs vary depending upon the location of the utility (its horizontal location and its depth).

Consider the modeling of installation cost for water utility. The horizontal locations \( i \) are divided into three areas pavement, between and sidewalk, which define the locations that are under the pavement, between pavement and sidewalk, and under the sidewalk respectively. They are defined by a membership function as shown in Figure 7. In this the horizontal location, pavement is defined by the membership function \( \text{pimf} \ [0.973, 0.973, 1.83, 4.03] \). \( \text{Pimf} \) is build-in \( \pi \)-shaped curved membership function in Matlab fuzzy logic toolbox. Similarly, normal and sidewalk are defined by membership functions \( \text{pimf} \ [1.62, 3.71, 7.71, 10.5] \) and \( \text{pimf} \ [7.36, 9.13, 12, 12] \) respectively. The vertical location \( j \) is defined as low, average and deep depending upon the depth of the utilities’ location and they are defined by membership functions \( \text{pimf} \ [0.9067, 0.9067, 1.76, 2.853] \), \( \text{pimf} \ [1.36, 2.573, 3.107, 4.693] \) and \( \text{pimf} \ [3.22, 4.16, 5, 5] \) respectively as shown in Figure 8. Likewise, the installation costs are also defined at six different levels as very low, low, medium, average, high and very high and defined by membership functions \( \text{trimf} \ [60.5 64.7 71.3] \), \( \text{trimf} \ [68.7 73.5 78.9] \), \( \text{trimf} \ [78.6 84.32 91.2] \), \( \text{trimf} \ [88.24 94.48 100.5] \), \( \text{trimf} \ [98.4 104.1 110.4] \), and \( \text{trimf} \ [105.9 114.3 120] \) respectively as shown in Figure 9. \( \text{Trimf} \) represents a triangular membership function.
Figure 7: Horizontal Locations of Water Utility

Figure 8: Vertical Locations of Water Utility
The horizontal location, vertical location and the installation costs are connected together by a set of rules based on the Mamdani concept (22), which uses the "if and then" principle for setting up rules. This rule calculates the installation cost at each location according to its horizontal location and the vertical location. For example, if the horizontal location is pavement and the vertical location is deep, then the installation cost is very high as shown in Figure 10. The value of the installation cost depends on the membership of that location with the pavement set and deep set. The rules are also explained in Figure 11 with the help of rule viewer in Matlab Fuzzy Logic Toolbox. The fuzzy surface of the water utility is given in Figure 12.
Figure 10: Rules for the Fuzzy Numbers

Figure 11: Rule Viewer for the Fuzzy Numbers
Figure 12: Fuzzy Surface of Water Utility
4.5. Simulation Model

The model is simulated using Matlab software. The simulation gets inputs about the utility system and then finds the location for the utilities so that the total cost of the utility system is least. The model has modeled the different cost factors as discussed earlier. Installation costs are modeled as fuzzy numbers using the fuzzy logic toolbox in Matlab. Maintenance costs are modeled as uniform random numbers using the \texttt{unifrnd} function, which is the function for uniform random number generator. Similarly accident costs are modeled as exponential random numbers using the \texttt{exprnd} function. All these cost factors are stored as matrices, which give the costs at all possible locations for different types of utilities.

The inputs for the model are the following:

1. Available area for the placement of the utilities.
2. Number of utilities.
3. Types of utilities.
4. Characteristics of the utilities such as size, clearance, below sidewalk, stacking, etc.

The steps that are followed by the model for finding the location for placement of the utilities are

1. The total available area is divided into grids of equal size 0.5 ft.
2. Possible locations for all the utilities are found using characteristics below sidewalk, below pavement, minimum cover, and maximum depth.
3. Utilities are placed in one of their possible locations.
4. A value of 1.5 is added to all the grids where utilities are placed.

5. A value of 0.5 is added to all the grids in clearance area and stacking.

6. Checks whether the difference between water and sewer utility is greater than 4 in both horizontal (h) and vertical (v) locations. This ensures the distance between water and sewer utility is greater than 2 ft.

7. Checks whether the value of all the grids are less than or equal to 2 and all the true cases are considered as possible scenarios and the false cases are left out.

8. Total cost of the utility system is found for this possible scenario.

9. Steps 3 to 8 are repeated for all the possible combination of utility locations.

10. Minimum cost of all the possible scenarios is found. The location of the utilities in this scenario is the solution.

The model gives the location for the utilities for the placement of utilities as the output. The model will take 45 minutes to find the solution for a utility system with six utilities in a Pentium III computer with processing speed 750 MHz.
5. RESULTS

The decision-making model in this research finds the location for placing the utilities in the highway corridor. The model was tested with a sample utility system model, which has six utilities as discussed in Chapter 4. The characteristics of the utilities in the sample utility system are given in the Table 1. The model was run with the same parameters for 25 runs. During each run, the model locates all the six utilities in all the possible locations and finds the total cost of the utility system for each combination of possible locations. From all these costs of the possible combinations of utility locations, the good locations for the utilities are found by determining the locations at which the total cost of the utility system is the lowest. For each run the solution may vary since some of the cost coefficients are modeled as probabilistic random numbers. Therefore, by running the model with the same parameters for the utility system, the final solution can be found by finding the most occurring solution. The most occurring solution is considered to be the final solution for the utility system considered.

The different solutions that were achieved during the running of the model are shown in Table 2. In Table 2, the index \( h \) represents the horizontal location and the index \( v \) represents the vertical location of the utilities. The final solution is also given as solution number 8 in the Table 2. This solution that occurred most often in the 25 runs was made with the parameters in Table 1. The S-matrix for this solution is also given in Figure 12. Figure 13 gives the utility system with all
six utilities placed in the locations that are determined by the decision-making model developed in this research.

Table 1: Characteristics of the Utilities

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Water</th>
<th>Sewer</th>
<th>Electric</th>
<th>Telephone 1</th>
<th>Telephone 2</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size in Diameter</td>
<td>1 ft</td>
<td>1.5</td>
<td>.5</td>
<td>.4</td>
<td>0.8</td>
<td>.4</td>
</tr>
<tr>
<td>Horizontal clearance</td>
<td>1 ft</td>
<td>1 ft</td>
<td>.5 ft</td>
<td>.5 ft</td>
<td>.5 ft</td>
<td>.5 ft</td>
</tr>
<tr>
<td>Vertical clearance</td>
<td>1 ft</td>
<td>1 ft</td>
<td>.5 ft</td>
<td>.5 ft</td>
<td>.5 ft</td>
<td>.5 ft</td>
</tr>
<tr>
<td>Minimum depth</td>
<td>3 ft</td>
<td>3 ft</td>
<td>3 ft</td>
<td>3 ft</td>
<td>3 ft</td>
<td>2 ft</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>6 ft</td>
<td>6 ft</td>
<td>5 ft</td>
<td>5 ft</td>
<td>5 ft</td>
<td>4 ft</td>
</tr>
<tr>
<td>Stacking</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Below sidewalk</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Below pavement</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Other</td>
<td>2 ft</td>
<td>2 ft</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>clearance with sewer</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clearance with water</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Horizontal (h) And Vertical (v) Locations for Each Utility in Different Runs of the Model

<table>
<thead>
<tr>
<th>Run No</th>
<th>Water</th>
<th>Sewer</th>
<th>Electric</th>
<th>Telephone 1</th>
<th>Telephone 2</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
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<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
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<tr>
<td>3</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3</td>
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<tr>
<td>4</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>4</td>
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</tr>
<tr>
<td>5</td>
<td>8</td>
<td>5</td>
<td>2</td>
<td>2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

For the final solution the costs are:

- Installation costs = $488/m
- Maintenance costs = $283/m
- Accident costs = $93/m
- Overall cost function = 347 no units
Figure 13: S Matrix When Utilities are Placed in Locations Given by the Model

In all these solutions, there are only small changes in locations of one or two utilities. These small changes are due to the randomness of the cost coefficients. By analyzing all these solutions after each run, all these solutions follow all the constraints and the characteristics of their utilities and the utility system. In the solutions, there is always one utility at each location. Utilities were not located in clearance space of any other utility. There are no utilities above or below the electric utility since stacking is not allowed for electric utility. Electric utility, telephone 1 utility, telephone utility 2 and natural gas utility were not placed under pavement or sidewalk since that is not allowed according to the constraints of the utility system. There is a clearance of two feet between water utility and sewer utility.
Similarly, results were obtained for different scenarios where the number of utilities, constraints and the characteristics of utilities are different. In all cases the final results are locations for utilities and the overall cost at these locations are minimum. Thus, it will reduce the cost to the public for the utilities as a whole. The solutions also follow all the constraints of the utility system in all the cases irrespective of changes in the parameters of the utility system.
6. CONCLUSION

In this research, a model was developed for finding good locations for placing utilities in the utility corridors along the highways and roads. There has been very little research done in this area. In most of the previous research, the problem was seen only as a construction problem. Also, each utility is considered separately and so the overall cost for the public is usually greater than it should be. Even the improvements done by some of the utility firms are only for their facilities without the consideration of the other utilities in the utility corridor. This research implements some of the optimization techniques and mathematical concepts to solve this problem. In this research, the utility system is considered as a system, each utility is considered as an entity of the system and the rules and regulations of the public agencies are considered as constraints to the solution for this problem.

The decision-making model uses weighted coefficient optimization that considers various factors that influence the placement of the utilities in the ROW. Also, the model incorporates the cost coefficients of the objective functions according to its characteristics. Fuzzy set theory was applied to manage uncertainty and incompleteness in the data of the installation costs. Other costs are modeled as probabilistic random numbers such as uniform or exponential random numbers depending on their characteristics. The algorithm considers each and every possible location for all the utilities while finding the location for
placement of the utilities. An iterative process is used to find the location at which the cost of the system will be least among all the possible solutions. The iterative process is repeatedly run with the same parameters and the most repeated solution is considered as the final solution. Several run are needed because there are many probabilistic random numbers and by repeating the runs a more reliable solution can be achieved.

Using this decision-making model, good locations can be found for locating utilities in the utility corridor such that the total cost of the utility corridor will be minimum while at the same time all the utility constraints are strictly followed. The model performance was tested with different problems. In some problems different combinations of utilities were used, in some situations, characteristics of the utilities were altered, and in some the constraints were varied and also the number of utilities was changed. In all these cases the model gave reliable results. This decision-making model is also very flexible in that characteristics of the utility system and their costs can be changed according to the requirements of the user.

6.1. Limitations

This research also has some limitations. Although, the decision-making model is based on constraints and characteristics collected from people of various appropriate organizations, some of these may not be followed exactly by the present public agencies and utility firms. Also, it is not possible to validate the results by testing it against a real-world problem.
The model takes quite a long time to solve the medium sized problems. For example, a problem with 6 utilities in the utility system took nearly 45 minutes for a single run in a Pentium III processor with processing speed of 750 MHz. The model will require considerably longer time when solving larger problems.
7. FUTURE WORK

As discussed earlier, this research is very new and there has been little research done in this area. In this research, the problem of placing the utilities in the right location in the ROW of the roads and highways was approached as an optimization problem and solved using a weighted coefficient optimization approach. Several areas of future works are possible related to this research. Some of the future extensions that can be done are discussed.

1. This research was done only for utility lines in straight roads and highways. This can be extended to utilities in curves and intersections of the roads and highways.

2. New utility lines are the only ones considered in this research and it can be extended to existing utility lines also.

3. The model can be made to get more accurate results by getting more data related to the utility system. Extensive data collection is required for achieving this.

4. A flexible user interface can be developed so that the end users who have less programming and technical knowledge can use the decision-making model easily. This can be done using programming languages like Visual Basic.
5. Since the model takes considerable time to solve large problems. The model can be programmed in some other software that can run the model faster.
REFERENCES


5. Dr. Kranc, S. C., Dr. Miller, W. A.,”The Optimum Placement of Utilities within FDOT Right of Way”, Sponsored by Florida DOT.


BIBLIOGRAPHY


Appendix A. Matlab Program for the Model

% Installation cost
a=readfis('water.fis');
for i=1:11
    for j=1:5
        icw(i, j) =evalfis([i j], a);
    end
end

a=readfis('electric.fis');
for i=1:8
    for j=1:4
        ice(i, j) =evalfis([i j], a);
    end
end

a=readfis('sewer.fis');
for i=1:10
    for j=1:4
        ics(i, j) =evalfis([i j], a);
    end
end

a=readfis('telephone1.fis');
for i=1:8
    for j=1:4
        ict1(i,j) =evalfis([i j], a);
    end
end
a=readfis('telephone2.fis');
for i=1:8
    for j=1:4
        ict2(i,j) =evalfis([i j], a);
    end
end

a=readfis('gas.fis');
for i=1:8
    for j=1:4
        icg(i, j) =evalfis([i j], a);
    end
end

% maintenance cost
Appendix A (Continued)
mwl=transpose ([50 50 67 68 70 70 70 70 70 70 69
45 46 47 56 55 57 57 58 55 53 50
36 37 40 41 42 42 43 44 41 40 40
31 33 36 37 37 37 37 37 37 35 35
20 21 25 29 31 31 31 32 31 31 29]);
msl=transpose ([70 73 89 88 90 94 91 90 86 80
65 65 67 68 70 70 70 70 70 70
46 47 50 51 52 53 54 51 50
31 33 36 37 37 37 37 37 37 35 35]);
mt1l=transpose ([45 46 56 55 57 57 58 55
36 37 41 42 42 44 44 41
31 33 37 37 37 37 37 37
20 21 29 31 31 31 32 31]);
mt2l=transpose ([65 65 67 68 70 70 70
45 46 47 56 55 57 57
36 37 40 41 42 42 43
31 33 36 37 37 37 35
20 21 29 31 31 31 29]);
mgl=transpose ([50 50 67 68 70 70 70 69
45 46 47 56 58 55 53 50
36 37 40 41 42 44 42 42
31 33 36 37 37 37 35
20 21 29 31 31 31 32 31]);
mel=transpose ([45 46 56 55 57 57 58 55
36 37 41 42 42 44 44 41
31 33 37 37 37 37 37
20 21 29 31 31 31 32 31]);

% accidental cost
aw=transpose ([50 50 67 68 70 70 70 70 70 70 69
45 46 47 56 55 57 57 58 55 53 50
36 37 40 41 42 42 43 44 41 40 40
31 33 36 37 37 37 37 37 37 35 35
20 21 25 29 31 31 31 32 31 31 29]);
as=transpose ([70 73 89 88 90 94 91 90 86 80
65 65 67 68 70 70 70 70 70 70
46 47 50 51 52 53 54 51 50
31 33 36 37 37 37 37 37 37 35 35]);
at1=transpose ([45 46 56 55 57 57 58 55
36 37 41 42 42 44 44 41
31 33 37 37 37 37 37 37
20 21 29 31 31 31 32 31]);
at2=transpose ([65 65 67 68 70 70 70
45 46 47 56 55 57 57
36 37 40 41 42 42 43
31 33 40 41 42 44 42 42]);
ag=transpose ([50 50 67 68 70 70 70 69
45 46 47 56 58 55 53 50
36 37 40 41 42 44 42 42])
Appendix A (Continued)

\[
\begin{bmatrix}
31 & 33 & 36 & 37 & 37 & 37 & 35 & 35 \\
45 & 46 & 56 & 55 & 57 & 57 & 58 & 55 \\
36 & 37 & 41 & 42 & 42 & 43 & 44 & 41 \\
31 & 33 & 37 & 37 & 37 & 37 & 37 & 37 \\
20 & 21 & 29 & 31 & 31 & 31 & 32 & 31 \\
\end{bmatrix}
\]

\[ae=\text{transpose}([45, 46, 56, 55, 57, 57, 58, 55, 36, 37, 41, 42, 42, 43, 44, 41, 31, 33, 37, 37, 37, 37, 37, 37, 20, 21, 29, 31, 31, 31, 32, 31]);\]

finalcost=100000;

for iw=1:11
    for jw=1:5
        for ie=1:8
            for je=1:4
                for is=1:10
                    for js=1:4
                        for it1=1:8
                            for jt1=1:4
                                for it2=1:7
                                    for jt2=1:3
                                        for ig=1:8
                                            for jg=1:4
                                                cost=0;
                                                s=zeros ([16, 12]);

                                                %water
                                                iws=iw+2;
                                                jws=jw+4;
                                                % placing water utility
                                                for i=iws: iws+1
                                                    for j=jws: jws+1
                                                        s (i, j) =1.5;
                                                    end
                                                end

                                                %clearance for water utility
                                                for i=iws-2: iws+3
                                                    for j=jws-2: jws+3
                                                        s (i, j) =s (i, j) +0.5;
                                                    end
                                                end
                                            end
                                        end
                                    end
                                end
                            end
                        end
                    end
                end
            end
        end
    end
end
Appendix A (Continued)

\%electric
ies=ie+4;
jes=je+4;
\% placing electric utility
for i=ies: ies
for j=jes: jes
    s (i, j) =s (i, j) +1.0;
end
end

\%clearance for electric utility
for i=ies-1: ies+1
for j=jes-1: jes+1
    s (i, j) =s (i, j) +0.5;
end
end

\% No stacking
for i=ies: ies
for j=1:12
    s (i, j) =s (i, j) +0.5;
end
end

\% sewer
iss=is+2;
jss=js+4;

\%Placing sewer utility
for i=iss: iss+2
for j=jss: jss+2
    s (i, j) =s (i, j) +1.5;
end
end

\% clearance for sewer utility
for i=iss-2: iss+4
for j=jss-2: jss+4
    s (i, j) =s (i, j) +0.5;
end
end
Appendix A (Continued)
% telephone 1

it1s=it1+4;
jt1s=jt1+2;

% placing telephone 1 utility
for i=it1s:it1s
    for j=jt1s:jt1s
        s (i, j) =s (i, j) +1.5;
    end
    end

% clearance for telephone 1 utility
for i=it1s-1:it1s+1
    for j=jt1s-1:jt1s+1
        s (i, j) =s (i, j) +0.5;
    end
    end

% telephone 2

it2s=it2+4;
jt2s=jt2+2;

% placing telephone 2 utility
for i=it2s:it2s+1
    for j=jt2s:jt2s+1
        s (i, j) =s (i, j) +1.5;
    end
    end

% clearance for telephone 2 utility
for i=it2s-1:it2s+2
    for j=jt2s-1:jt2s+2
        s (i, j) =s (i, j) +0.5;
    end
    end

% gas
igs=ig+4;
jgs=jg+2;

% placing gas utility
for i=igs: igs
Appendix A (Continued)
for j=jgs: jgs
    s(i, j) = s(i, j) + 1.5;
end
end

% clearance for gas
for i=igs-1: igs+1
    for j=jgs-1: jgs+1
        s(i, j) = s(i, j) + 0.5;
    end
end

% checking s matrix
for i=1:16
    for j=1:12
        if s(i, j)>2
            cost=10000;
        end
    end
end

% calculating cost
icost=icw(iw,jw)+ice(ie,je)+ics(is,js)+ict1(it1,jt1)+ict2(it2,jt2)+icg(ig,jg);
mcost=unifrnd(mwl(iw,jw),10+mwl(iw,jw))+unifrnd(mel(ie,je),10+mel(ie,je))+unifrnd(msl(is,js),10+msl(is,js))+unifrnd(mt1l(it1,jt1),10+mt1l(it1,jt1))+unifrnd(mt2l(it2,jt2),10+mt2l(it2,jt2))+unifrnd(mgl(ig,jg),10+mgl(ig,jg));
acost=exprnd(aw(iw,jw))+exprnd(ae(ie,je))+exprnd(as(is,js))+exprnd(at1(it1,jt1))+exprnd(at2(it2,jt2))+exprnd(ag(ig,jg));
tcost=cost+0.5*icost+0.2*acost+0.3*mcost

if tcost<finalcost
    finalcost=tcost
    finalicost=icost
    finalacost=acost
    finalmcost=mcost
    fiw=iw;
    fjw=jw;
    fje=je;
    fis=is;
    fjs=js;
    fit1=it1;
Appendix A (Continued)

```matlab
fjt1=jt1;
fit2=it2;
fjt2=jt2;
fig=ig;
fig=jg;
fs=s;
end
s=zeros ([16, 12]);
cost=0;
tcost=0;

end
end
end
end
end % telephone2 end
end
end
end
end
end
end % sewer end
end % water end
end
finalcost
finalicost
finalacost
finalmcost
fiw
fjw
fie
fje
fis
fjs
fit1
fjt1
fit2
fjt2
fig
fig
transpose (fs)
```
Appendix B. Modeling of Fuzzy Numbers

Water

1. Name            water
2. Type            mamdani
3. Inputs/Outputs  [2 1]
4. NumInputMFs     [3 3]
5. NumOutputMFs    6
6. NumRules        9
7. AndMethod       min
8. OrMethod        max
9. ImpMethod       min
10. AggMethod      max
11. DefuzzMethod   centroid
12. InLabels       i_value
13. j_value
14. OutLabels      installation_cost
15. InRange        [1 11]
16. [1 5]
17. OutRange       [60 120]
18. InMFLabels     pavement
19. ROW
20. sidewalk
21. near
22. average
23. deep
24. OutMFLabels    medium
25. average
26. highest
27. very_less
28. medium_average
29. high
30. InMFTypes      pimf
31. pimf
32. pimf
33. pimf
34. pimf
35. pimf
36. OutMFTypes     trimf
37. trimf
38. trimf
39. trimf
40. trimf
41. trimf
Appendix B (Continued)

42. InMFPParams   [0.973 0.973 1.83 4.03]
43.                  [1.62 3.71 7.71 10.5]
44.                  [7.36 9.13 12 12]
45.                  [0.9067 0.9067 1.76 2.853]
46.                  [1.36 2.573 3.107 4.693]
47.                  [3.22 4.16 5 5]
48. OutMFPParams    [68.7 73.5 78.9 0]
49.                  [88.24 94.48 100.5 0]
50.                  [105.9 114.3 120 0]
51.                  [60.45 64.65 71.25 0]
52.                  [78.6 84.32 91.2 0]
53.                  [98.4 104.1 110.4 0]

Sewer

1. Name             sewer
2. Type             mamdani
3. Inputs/Outputs   [2 1]
4. NumInputMFs      [3 3]
5. NumOutputMFs     6
6. NumRules         9
7. AndMethod        min
8. OrMethod         max
9. ImpMethod        min
10. AggMethod       max
11. DefuzzMethod    centroid
12. InLabels        i_value
13.                  j_value
14. OutLabels       installation_cost
15. InRange         [1 10]
16.                  [1 4]
17. OutRange        [75 150]
18. InMFLables      pavement
19.                  ROW
20.                  sidewalk
21.                  near
22.                  average
23.                  deep
24. OutMFLables     medium
25.                  average
26.                  highest
27.                  very_less
28.                  medium_average
29.                  high
30. InMFTypes       pimf
Appendix B (Continued)

31. pimf
32. pimf
33. pimf
34. pimf
35. pimf
36. OutMFTypes trimf
37. trimf
38. trimf
39. trimf
40. trimf
41. trimf
42. InMFParams [0.9757 0.9757 1.747 3.727]
43. [1.558 3.439 7.039 9.55]
44. [6.724 8.317 10.9 10.9]
45. [0.93 0.93 1.57 2.39]
46. [1.27 2.18 2.58 3.77]
47. [2.665 3.37 4 4]
48. OutMFParams [85.88 91.88 98.63 0]
49. [110.3 118.1 125.6 0]
50. [132.4 142.9 150 0]
51. [75.56 80.81 89.06 0]
52. [98.25 105.4 114 0]
53. [123 130.1 138 0]

Electric

1. Name electric
2. Type mamdani
3. Inputs/Outputs [2 1]
4. NumInputMFs [3 3]
5. NumOutputMFs 6
6. NumRules 9
7. AndMethod min
8. OrMethod max
9. ImpMethod min
10. AggMethod max
11. DefuzzMethod centroid
12. InLabels i_value
13. j_value
14. OutLabels installation_cost
15. InRange [1 8]
16. [1 4]
17. OutRange [35 75]
18. InMFLabels pavement
19. ROW
Appendix B (Continued)
20. sidewalk
21. near
22. average
23. deep
24. OutMFLabels medium
25. average
26. highest
27. very_less
28. medium_average
29. high
30. InMFTypes pimf
31. pimf
32. pimf
33. pimf
34. pimf
35. pimf
36. OutMFTypes trimf
37. trimf
38. trimf
39. trimf
40. trimf
41. trimf
42. InMFParams [0.9811 0.9811 1.581 3.121]
43. [1.434 2.897 5.697 7.65]
44. [5.452 6.691 8.7 8.7]
45. [0.93 0.93 1.57 2.39]
46. [1.27 2.18 2.58 3.77]
47. [2.665 3.37 4 4]
48. OutMFParams [40.84 44.04 47.64 0]
49. [53.8 57.96 62.04 0]
50. [65.64 71.24 75 0]
51. [35.32 38.12 42.52 0]
52. [47.4 51.24 55.8 0]
53. [60.6 64.44 68.6 0]

Telephone 1
1. Name telephone1
2. Type mamdani
3. Inputs/Outputs [2 1]
4. NumInputMFs [3 3]
5. NumOutputMFs 6
6. NumRules 9
7. AndMethod min
8. OrMethod max
Appendix B (Continued)
9. ImpMethod  min
10. AggMethod  max
11. DefuzzMethod  centroid
12. InLabels  i_value
13.  j_value
14. OutLabels  installation_cost
15. InRange  [1 8]
16.  [1 4]
17. OutRange  [40 80]
18. InMFLabels  pavement
19.  ROW
20.  sidewalk
21.  near
22.  average
23.  deep
24. OutMFLabels  medium
25.  average
26.  highest
27.  very_less
28.  medium_average
29.  high
30. InMFTypes  pimf
31.  pimf
32.  pimf
33.  pimf
34.  pimf
35.  pimf
36. OutMFTypes  trimf
37.  trimf
38.  trimf
39.  trimf
40.  trimf
41.  trimf
42. InMFParams  [0.9811 0.9811 1.581 3.121]
43.  [1.434 2.897 5.697 7.65]
44.  [5.452 6.691 8.7 8.7]
45.  [0.93 0.93 1.57 2.39]
46.  [1.27 2.18 2.58 3.77]
47.  [2.665 3.37 4 4]
48. OutMFParams  [45.8 49 52.6 0]
49.  [58.83 62.99 67 0]
50.  [70.6 76.2 80 0]
51.  [40.3 43.1 47.5 0]
52.  [52.4 56.21 60.8 0]
53.  [65.6 69.4 73.6 0]
Appendix B (Continued)

Telephone 2

1. Name telephone2
2. Type mamdani
3. Inputs/Outputs [2 1]
4. NumInputMFs [3 3]
5. NumOutputMFs 6
6. NumRules 9
7. AndMethod min
8. OrMethod max
9. ImpMethod min
10. AggMethod max
11. DefuzzMethod centroid
12. InLabels i_value
13. j_value
14. OutLabels installation_cost
15. InRange [1 8]
16. [1 4]
17. OutRange [40 80]
18. InMFLabels pavement
19. ROW
20. sidewalk
21. near
22. average
23. deep
24. OutMFLabels medium
25. average
26. highest
27. very_less
28. medium_average
29. high
30. InMFTypes pimf
31. pimf
32. pimf
33. pimf
34. pimf
35. pimf
36. OutMFTypes trimf
37. trimf
38. trimf
39. trimf
40. trimf
41. trimf
42. InMFPparams [0.9811 0.9811 1.581 3.121]
Appendix B (Continued)

43.                  \[1.434 2.897 5.697 7.65\]
44.                  \[5.452 6.691 8.7 8.7\]
45.                  \[0.93 0.93 1.57 2.39\]
46.                  \[1.27 2.18 2.58 3.77\]
47.                  \[2.665 3.37 4.4\]
48. OutMFParams      \[45.8 49 52.6 0\]
49.                  \[58.83 62.99 67 0\]
50.                  \[70.6 76.2 80 0\]
51.                  \[40.3 43.1 47.5 0\]
52.                  \[52.4 56.21 60.8 0\]
53.                  \[65.6 69.4 73.6 0\]

Gas

1.  Name             gas
2.  Type             mamdani
3.  Inputs/Outputs   \[2 1\]
4.  NumInputMFs      \[3 3\]
5.  NumOutputMFs     6
6.  NumRules         9
7.  AndMethod        min
8.  OrMethod         max
9.  ImpMethod        min
10. AggMethod        max
11. DefuzzMethod     centroid
12. InLabels         i_value
13.                  j_value
14. OutLabels        installation_cost
15. InRange          \[1 8\]
16.                  \[1 4\]
17. OutRange         \[100 150\]
18. InMFLabels       pavement
19.                  ROW
20.                  sidewalk
21.                  near
22.                  average
23.                  deep
24. OutMFLabels      medium
25.                  average
26.                  highest
27.                  very_less
28.                  medium_average
29.                  high
30. InMFTypes        pimf
31.                  pimf
Appendix B (Continued)

32. pimf
33. pimf
34. pimf
35. pimf
36. OutMFTypes trimf
37. trimf
38. trimf
39. trimf
40. trimf
41. trimf
42. InMFParams [0.9811 0.9811 1.581 3.121]
43. [1.434 2.897 5.697 7.65]
44. [5.452 6.691 8.7 8.7]
45. [0.93 0.93 1.57 2.39]
46. [1.27 2.18 2.58 3.77]
47. [2.665 3.37 4 4]
48. OutMFParams [107.3 111.3 115.8 0]
49. [123.5 128.7 133.8 0]
50. [138.3 145.3 150 0]
51. [100.4 103.9 109.4 0]
52. [115.5 120.3 126 0]
53. [132 136.8 142 0]