Improving Electrical System Management
For the Town of Boylston, MA

An Interactive Qualifying Project Report submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the Degree of Bachelor of Science

Submitted By:

Ryan Rainone
Jessica Nieves
Jonathan Frost

Sponsoring Agency:

Boylston Municipal Light Department

Submitted To:

Project Advisor:
Fabio Carrera

On-Site Liaisons:
Gary Harrington – *General Manager Boylston Municipal Light*
Mark Barakian – *Lead Lineman Boylston Municipal Light*

Date: May 2007

Email: ht-boylston07@wpi.edu

PROJECT WEBSITE: HTTP://ECE.WPI.EDU/~JN33JN/HT-BOYLSTON07.HTML

This project was conducted at Worcester Polytechnic Institute's City Lab as part of the Lab's "Hometown Initiative"

Authorship

This project was completed through equal contribution of each group member. The work represented in this report is original unless otherwise cited.

Ryan Rainone ________________________________

Jessica Nieves ________________________________

Jonathan Frost ________________________________

Acknowledgements

We would like to take the time to thank the following people, without which this project would not have been possible.

- Prof. Fabio Carrera, for his time, guidance and dedication as the advisor to this project throughout its completion
- Gary Harrington and his staff at the Boylston Municipal Light Department, for their help retrieving information and providing educational support
- The members of the Boylston Municipal Light Board for their time and continued support
- Charter Communications, for information regarding previously electronically mapped telephone poles
- David Sheridan and Joshua Gardiner of the Boylston Water IQP group, for the use of their Boylston building MapInfo layer and miscellaneous MapInfo help.

Abstract

This project was intended to assist the Boylston Municipal Light Department in modernizing their management and record keeping processes. After compiling information about the town's electric infrastructure, our project group developed a sustainable computerized system that allows for efficient record-keeping and information updating practices for the electric infrastructure. Furthermore, we made strong recommendations about how to better organize and execute daily maintenance tasks in a more proficient manner.

Executive Summary

One thing that cannot be ignored in today's society is the rapid growth of technology. Keeping up with these advances is a demanding task, but is to be expected. Presently, the Boylston Municipal Light Department is using a record keeping system based on a series of hand drawn map that are rarely updated. When the information on the maps is changed, oftentimes new maps are not made but rather the old information is merely crossed out on the existing map. Without accurate records the members of the light department are unaware of the condition of the current components; or where upgrades would be beneficial to the system. The goal of this project was to help the Town of Boylston's Electrical Department to improve its record keeping processes and make the system more efficient.

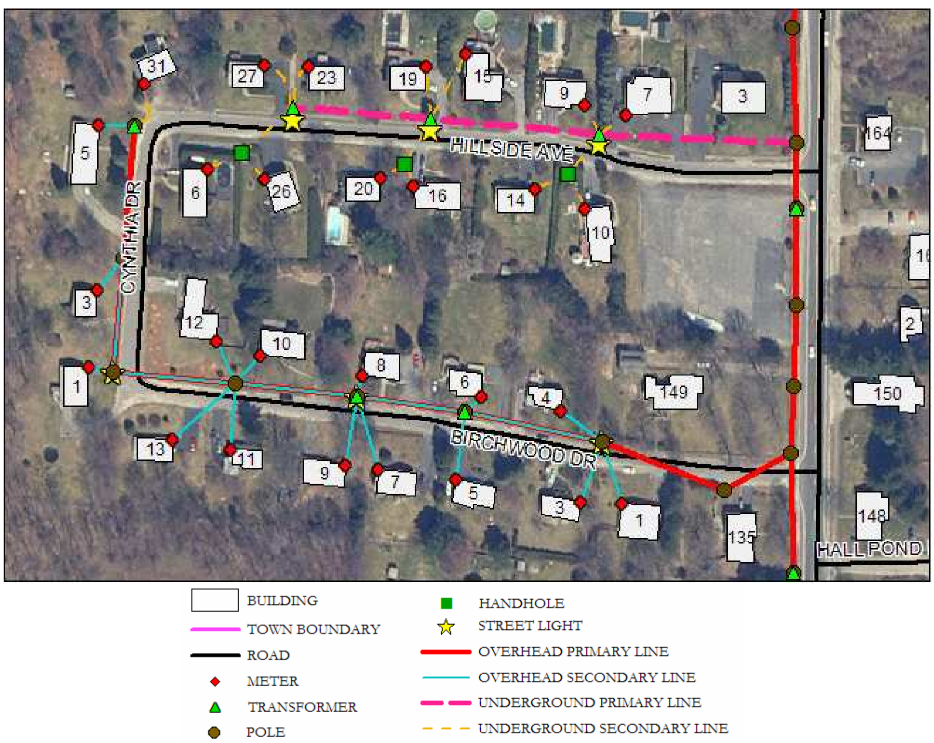


Figure 1: An Example of Geospatial Mapping for Boylston's Electric System

The first objective was to inventory the components of the system and the second was to estimate cost for upgrading aging and inefficient components. Poles, transformers, and lines were the inventoried components that needed upgrading.

In total 2,130 poles were inventoried into the databases and placed in the geospatial map. The result of all the poles inventoried can be found in Figure 2 on the right.

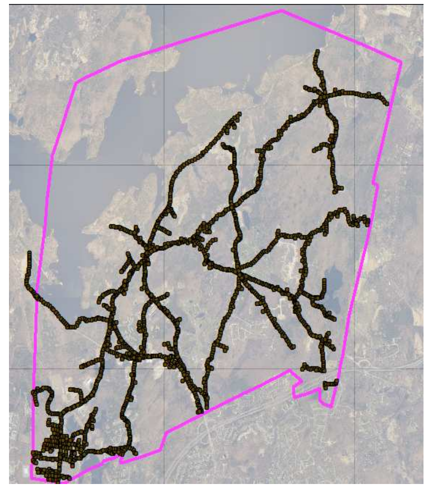


Figure 2: Map of Total Inventoried Poles (Quantity 2,130)

Aging poles within an electric system can cause unsafe conditions due to the high voltage lines they carry. By doing preventative maintenance to the system now, Boylston Municipal Light may be able to avoid costly downtime of their electric system later also increase customer satisfaction. A key point to note is that many of Boylston's oldest poles, as seen in the age distribution map in Figure 3, are found on core streets; such as Main Street, School Street, and Linden Street.

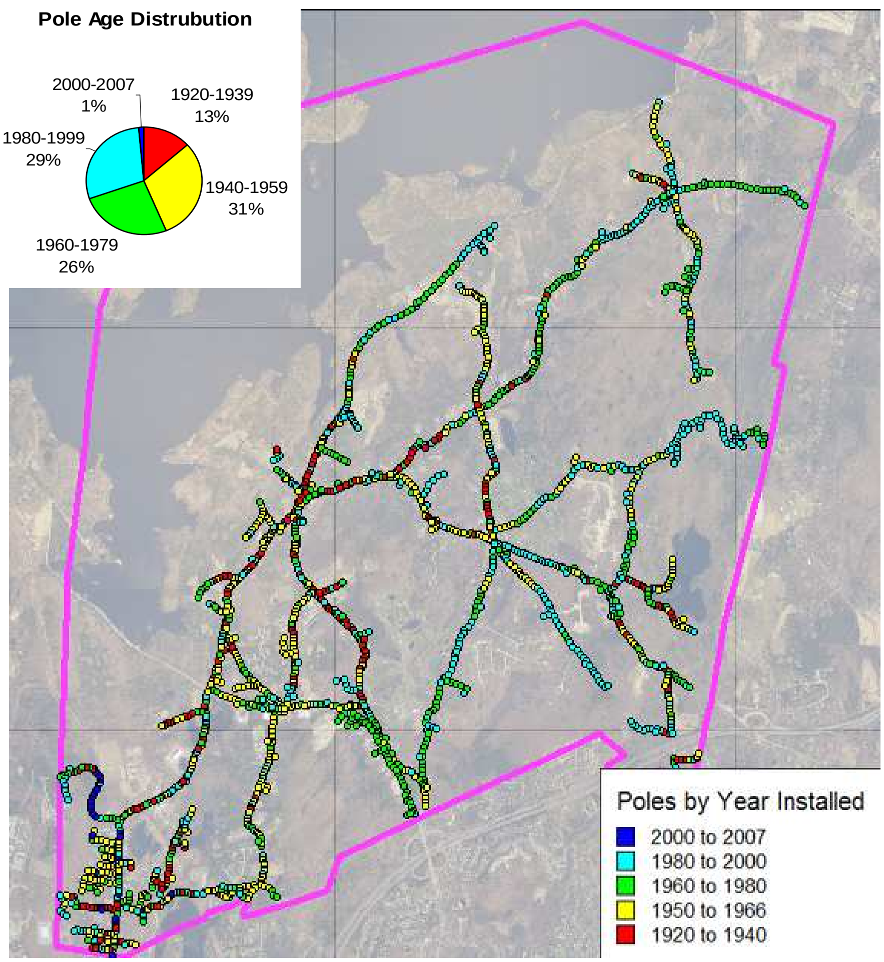


Figure 3: Inventoried Poles by Year Installed

If all poles shown in the age distribution map in Figure 3 that were installed before 1940 (the red poles) were to be replaced with an identical pole of the same height pole at today's market cost the total replacement would come to **$46,278**.

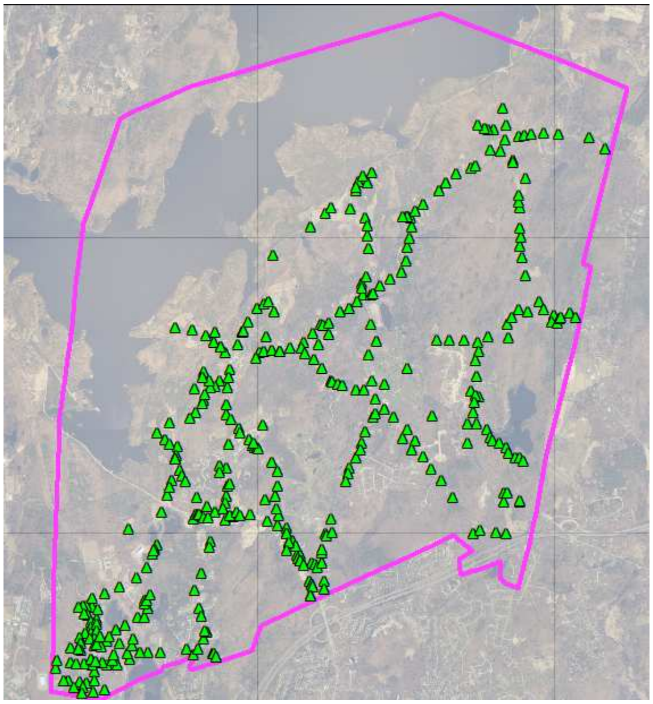


Figure 4: Map of All the Transformers Inventoried (Quantity 400)

For the most part, only pole mount transformers were inventoried. In total, 400 transformers were mapped and inventoried within the city limits of Boylston. To the left, Figure 4 is a map of all the transformers that were placed.

Old transformers lead to both lower efficiency and less reliability in an electrical system. Boylston's electrical system has 37 transformers spread throughout the town that were put into service before 1980, represented in Figure 5 by the red triangles. With the rising costs of energy, replacement of these transformers would led to less loss of profit on Boylston's behalf. Older transformers, when fully loaded, may only have an efficiency of 95% were as a new transformer bought today would have an efficiency of closer to 99%; this reduction of loses will led to greater profits and the transformers paying for themselves in the long run.

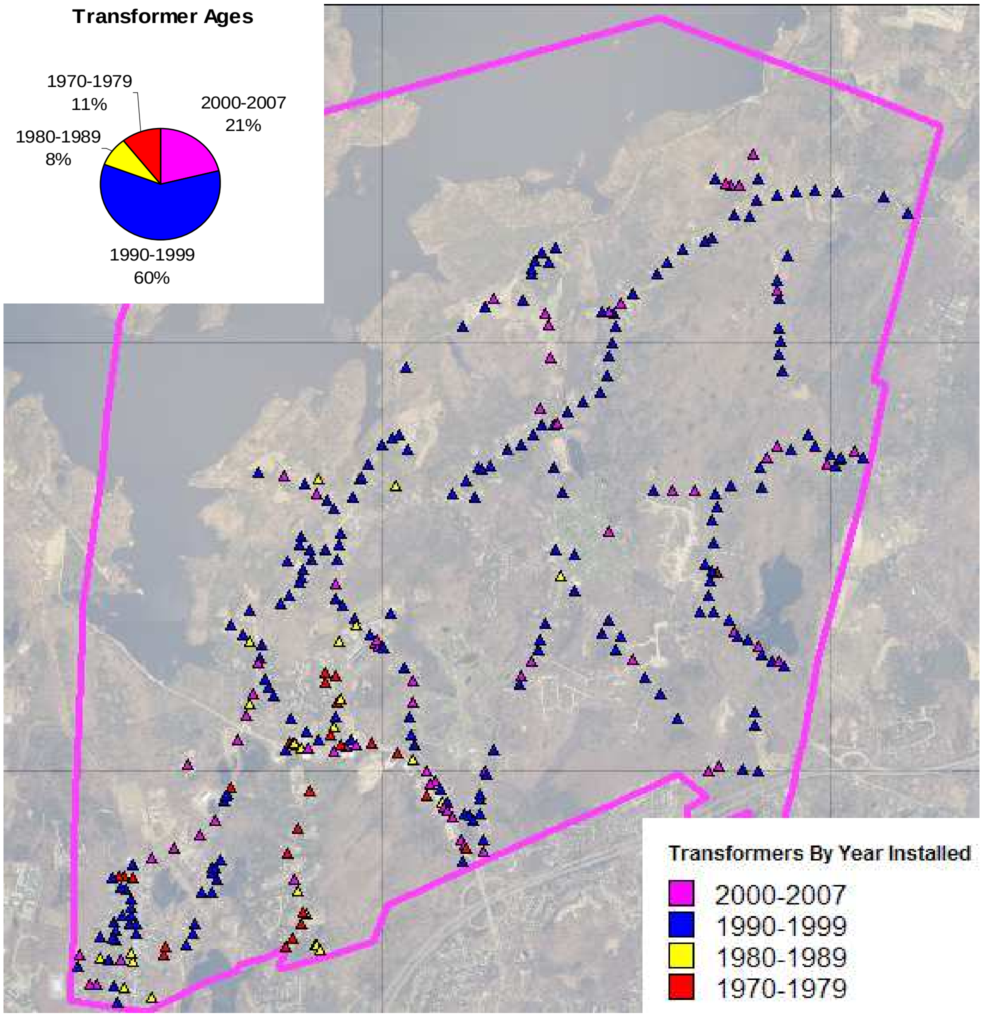


Figure 5: Inventoried Transformers by Year Installed

It is recommended is to replace 35 of the 37 old transformers with new models. The replacement of two largest size pad mount transformers is not advised due to cost constraints. If these 35 transformers were to be replaced with the same size unit at today's market price the cost would total **$44,400**.

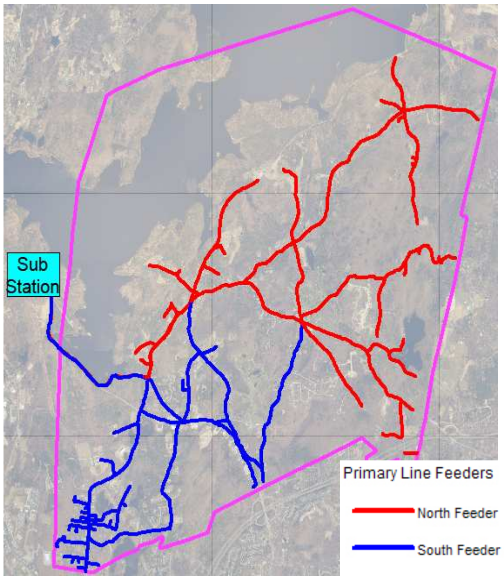


Figure 6 Overhead Primary Inventory Results (Quantity 41 miles)

The high voltage overhead primary lines in the town are broken up into two feeders that service the northern and southern parts of the town separately. The map in Figure 6 shows both feeders exit the sub-station in West Boylston side by side and go to feed all the transformers within the town. In total, 41 miles of overhead primary line were mapped, including 23.5 miles for the North Feeder and 17.5 miles for the South Feeder.

The main branches of the high voltage feeder system present in Boylston's electric infrastructure consist of 15 kilovolt aluminum tree wire of varies sizes. In Figure 7 below you can see the three sizes present with 3/0 being the smallest and 336 MCM being the largest wire size. In a perfect situation the wire size would remain consistent as the branches get farther away from the sub-station.

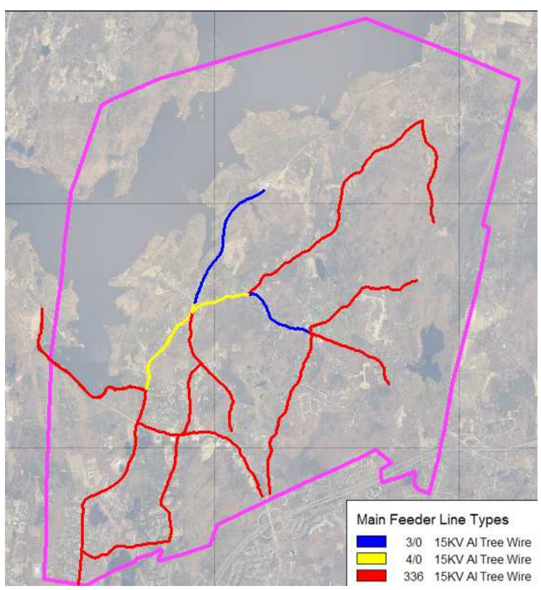


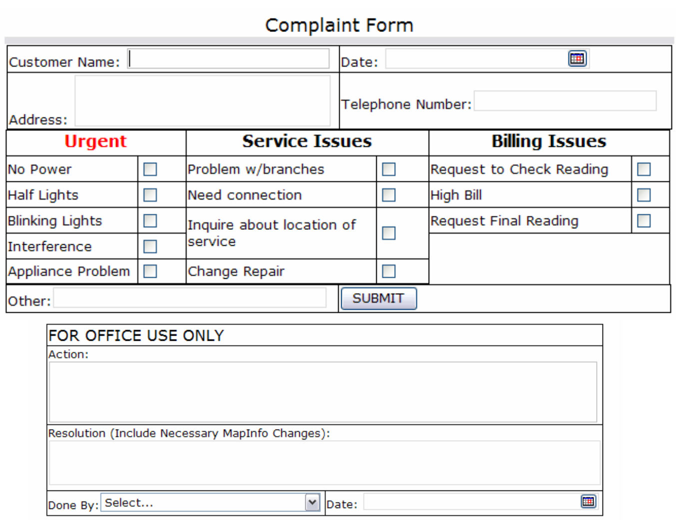
Figure 7: Main Feeders of Boylston's Electrical System Mapped by Size

For these reasons it is our recommendation to replace the 3/0 and 4/0 segments of line in the above map with larger 336 MCM size aluminum tree wire with a replacement cost of $1.86 per linear foot. Since this spaced tree wire requires three lines running parallel to each the necessary length of for this upgrade is three times the total segment length to be replacement making this a costly improvement. In total the blue and yellow portions on the above map represent just less than five miles of electrical lines in which it would cost **$143,173** to replace. The following table summarizes the cost for upgrade.

Component	Cost for Upgrade
Poles	46,278
Transformers	44,400
Lines	143,173
TOTAL COST FOR UPGRADE	**$233,851**

Figure 8: Total Cost for Upgrade of Components

The third objective for this project was to create an efficient system for keeping the database maintained and up to date. The problem with the current forms is that they are filed as paper copies, which take up a lot of space and make it difficult to remain organized. A solution was to create new forms that could be filled in and filed on a computer. The first form is for recording complaints or problems that customers have. The new form was split up into two parts; one for customer use and one for office use only. Once this form is filled out, it will be filed electronically. The new complaint form that was created can be seen below in Figure 9.


Complaint Form

Customer Name: Date:

Address: Telephone Number:

Urgent		Service Issues		Billing Issues	
No Power	☐	Problem w/branches	☐	Request to Check Reading	☐
Half Lights	☐	Need connection	☐	High Bill	☐
Blinking Lights	☐	Inquire about location of service	☐	Request Final Reading	☐
Interference	☐				
Appliance Problem	☐	Change Repair	☐		

Other: SUBMIT

FOR OFFICE USE ONLY

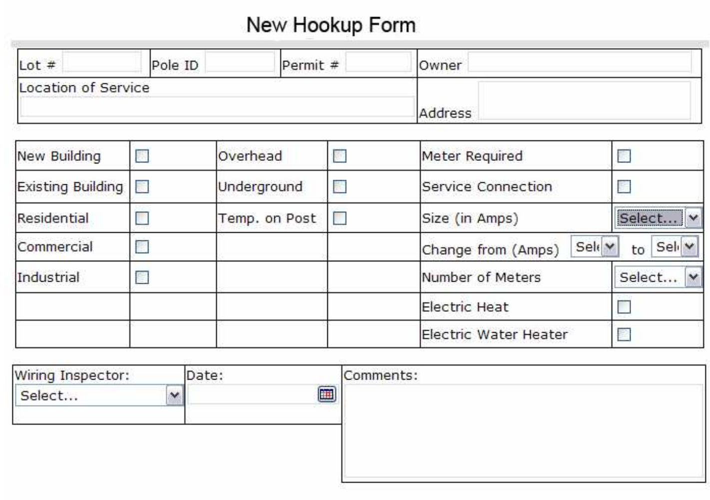
Action:

Resolution (Include Necessary MapInfo Changes):

Done By: Select... Date:

Figure 9: Redesigned Customer Complaint Form

The next form is used by the town wiring inspector to document the electrical situation at a residence. This form is filled out after electrical service is brought to a house, when the wiring inspector performs his inspection. Once the form is filled out it is given to the Light Department so they can record information regarding the residence, such as whether it is residential or commercial or whether or not it has electric heat. A copy of this improved form can be seen below in Figure 10.


New Hookup Form

Lot #	Pole ID	Permit #	Owner
Location of Service			Address

New Building	☐	Overhead	☐	Meter Required	☐
Existing Building	☐	Underground	☐	Service Connection	☐
Residential	☐	Temp. on Post	☐	Size (in Amps)	Select...
Commercial	☐			Change from (Amps)	Sel to Sel
Industrial	☐			Number of Meters	Select...
				Electric Heat	☐
				Electric Water Heater	☐

Wiring Inspector:	Date:	Comments:
Select...		

Figure 10: Updated New Hook-Up Form

The changes in both forms allow the Boylston Light Department to keep their system organized and up to date in an efficient manner.

The processes of the Light Department were also analyzed, and it became evident that the greatest amount of new data is created when a new subdivision is created in the town. Many new components and hook-ups are added to the system when subdivisions are built. Currently, the electrical systems found in subdivisions are sketched by hand on maps that are filed at the Light Department. The main part of this process that needed to be changed was at the end of the infrastructure placement. During this part of the process the work is done and all components are in their final places. It is at this point that the information about the subdivision can be imported into the database. But seeing as how the location of components could have changed since the beginning of this process, it is necessary to request the contractor to submit an electronic “as-built.” This is a copy of what the final subdivision looks like, usually drafted by an engineering firm. This request would have to be found in the planning regulations of the town. This change in regulations will have to come from the planning board because it would be unreasonable to have only the Light Department requiring the as-built. Once this system is in place it will be very simple for the Light Department to import information regarding new subdivisions into their database.

The fourth objective of this project was to investigate future expansion of the system, which was done by looking at the build out analysis of the town. Currently, the town of Boylston does not include the electrical system in their build-out analysis. One was created for their electrical system based on the present build-out conditions and numbers reported by the Central Mass Regional Planning Commission (CMRPC) as of 2006. It analyzes the system to establish if it is able to withstand maximum capacity of the town. The results can be seen in the table below.

	Current	At Maximum Capacity
Population	4,200	9,967
Customers	2,100	4,984
Maximum Peak	7,308 kW	17,340 kW
Maximum Peak per Customer (occurs at 7 PM)	3.48 kW	3.48 kW

Figure 11: Updated New Hook-Up Form

This analysis assumes that the commercial, residential, and industrial customers will increase in a linear fashion. The substation is able to withstand 24 MW; so therefore the system can handle the town of Boylston at its full build out population. The only downfall of the system is the layout of the primary lines or feeders from the substation.

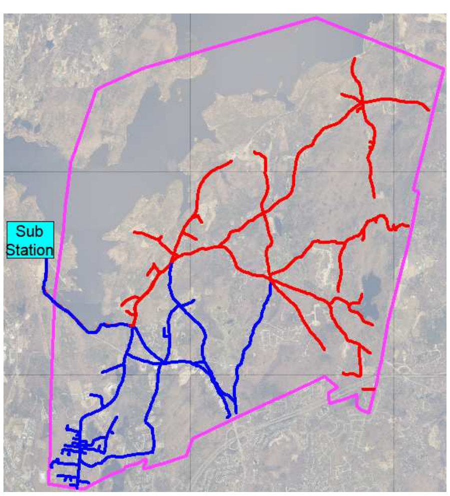


Figure 12: Current Feeder Design

The Boylston substation has 3 available feeders but is currently only using 2 of the 3. The blue feeder in Figure 13 is supplying the most densely populated area of Boylston; therefore the population of this section will not increase greatly. The northeast section of Boylston is where we expect the most new subdivisions to be built. As of now the loads on the feeders are somewhat balanced, however with the majority of the expansion occurring in the red feeder's vicinity the loads will become unbalanced. With that in mind, it is proposed that, in the future when the population increases, Boylston utilize its 3rd feeder to balance the loads into 3 sections as shown in Figure 13 below. Using the existing primary lines this process would not be difficult or costly and would create a more efficient layout for the future system when Boylston is at its maximum capacity.

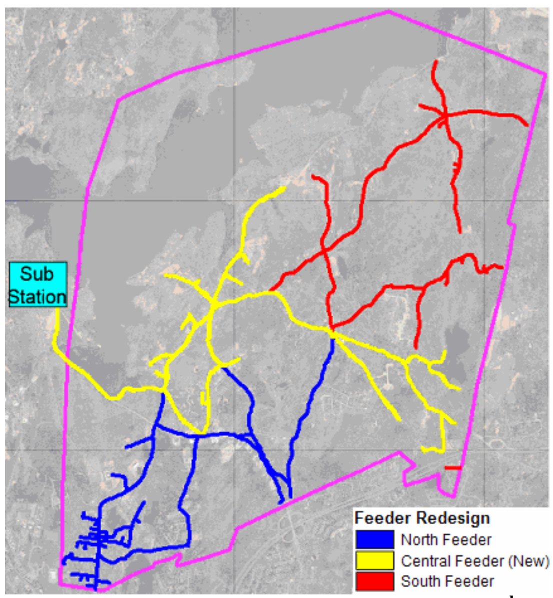


Figure 13: Proposed Feeder Redesign, Utilizing the 3rd Feeder

Due to time constraints and limited resources, there are some areas of this project that can still be explored further. Inventorying components was a difficult task that required pulling information together from many different sources. In order to ensure accuracy throughout mapping, great care was taken to confirm the exact location of components. This being said, the inventorying part of this project was not completed, but it was left at a stage that makes it easy to pick up. The following chart shows the progress that was made on the major components.

Component	Amount Inventoried	Estimated Total Amount	Amount Remaining
Poles	2130	2200	70
Transformers	400	598	198
Overhead Primary Lines	41 miles	45 miles	4 miles
Street Lights	49	150	101

Figure 14: Component Inventory Progress

The following is a list of components that were mapped primary in the Morningdale test area seen in Figure 1. Databases were created for these components and all that is left is placing them and filling in their information.

Components
Meters
Handholes
Overhead Secondary Lines
Underground Primary Lines
Underground Secondary Lines

Figure 15: Remaining Components to be Inventoried

Once the inventory of the entire system is complete it will be possible for the town to execute certain tasks that were previously very difficult. Two such tasks are fuse coordination and load balancing. Both of these will greatly improve the efficiency of the system. The databases and maps created in this project will make it possible to execute these tasks. Not only will this benefit the Light Department, but also its customers, who will experience less power outages. These can be a basis for a future project, or can be done by the Light Department themselves.

Finally, analysis of the processes and forms of the Light Department would not be complete without putting all of the pieces together. This could happen by using an online system to manage the Light Department. This system would include the forms and processes that were discussed in this report. In the future, customers will be able to log onto the Light Department website and report a complaint electronically using the new form. Once this is submitted, it will go into a database of complaints ranked by urgency. Once the work is completed, the second part of the complaint form will be filled out and stored electronically, and the complaint will be set to "Closed" in the database.

This is just one example of the new capabilities of the future system. Other examples include the potential for component analysis to be conducted on the system with a few mouse clicks, and of course, the ability to add components as necessary. All of these functions can be tailored to exactly what the Light Department needs and wants to be able to accomplish. An example of the user interface that will make all of this possible can be seen in Figure 16.

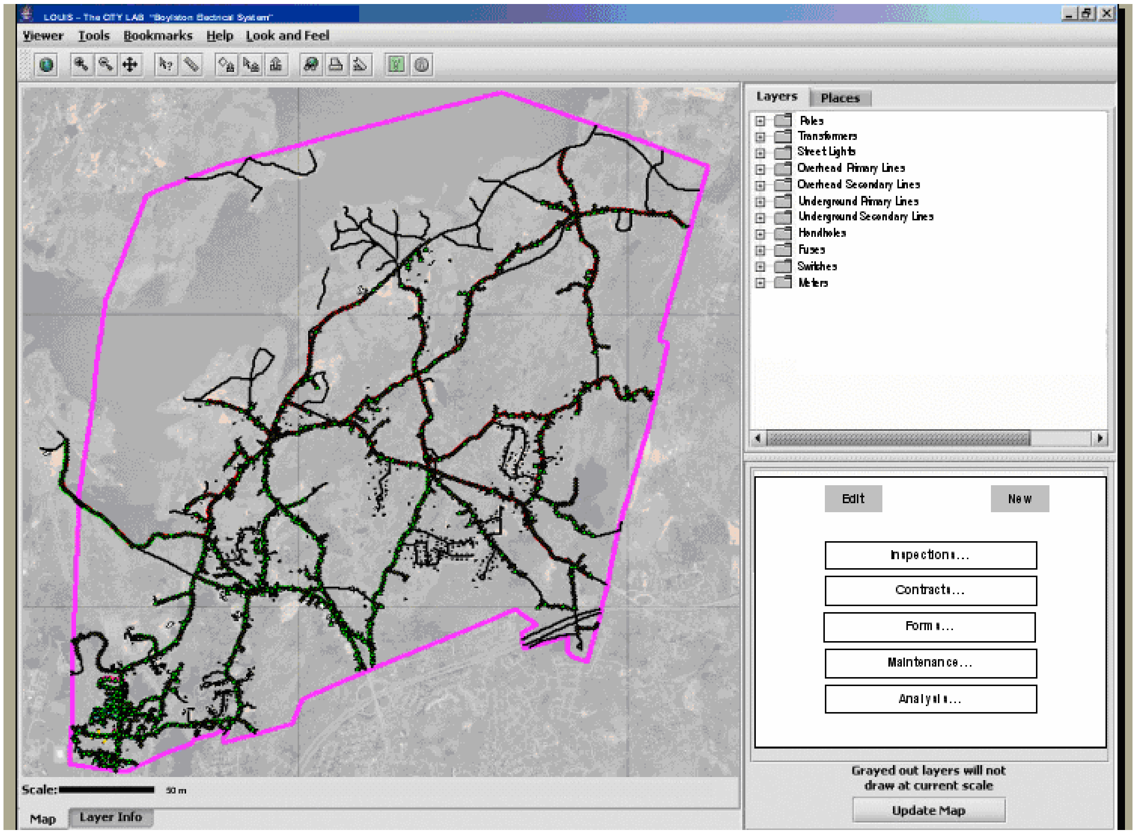


Figure 16: Mockup of the Future System

TABLE OF CONTENTS

TABLE OF FIGURES

1 Introduction

One thing that cannot be ignored in today's society is the rapid growth of technology. Keeping up with these advances is a demanding task, but is to be expected. Issues are quick to arise with smaller organizations and municipalities having the correct resources and access to these advances. This project will provide less technologically advanced countries, cities, or towns with an example on how to improve the organization of public infrastructure. In many ways an actual working model of the abilities of current technology will serve as a great resource to help other communities in the future to make similar infrastructure upgrades.

Since the development of public power systems in 1880, their presence across the United States has grown rapidly to 2,011 current working systems in 49 states (American Public Power Association 2006). Currently delivering energy to 14 percent of the nation's electric consumers, publicly owned power systems can be found from large cities to small communities (American Public Power Association 2002). With a large number of privately owned systems across the country filled with daily updates, it is hard to create an efficient solution for data management. The government is well aware of the importance of privately owned public power systems as represented in the Energy Policy Act of 2005. This act helps to protect public power companies financially by providing them with loans and tax breaks.

As a small business, the Municipal Light Department of the Town of Boylston, Massachusetts, has not had the available resources to implement a computerized record keeping system. The capabilities of a newer system would allow the Municipal Light Department to analyze and make changes in a more efficient manner. Since data entry times would be decreased, the town would not have to sacrifice updating their records due to a lack of personnel resources. Overall, the entire Town of Boylston and local population will benefit from the Municipal Light Department conducting their business in a more effective way.

Presently, the Boylston Municipal Light Department is using a record keeping system based on a series of hand drawn map that are rarely updated. When the information on the maps is changed, oftentimes new maps are not made but rather the old information is merely crossed out on the existing map. Without accurate records the members of the light department are unaware of the condition of the current components; or where upgrades would be beneficial to the system. The town would like to have this knowledge, but with the current system this is impossible.

The goal of this project is to help the Town of Boylston's Electrical Department to improve its record keeping processes. This will allow the department staff to manage and maintain the existing electrical system and better understand how it is currently working. By gathering the current paper records and any additional information from the field we will create an accurate database of the systems present state. Furthermore, to ensure the database is updated in the future we will propose a user-friendly module to enter changes and updates into the system. This newly organized information will allow us to make recommendations on future renovations and the reduction of energy consumption. This analysis will be beneficial to both the Boylston Municipal Light Department and its consumers.

2 Background Information

In order to fully understand the scope of this project, some background research was done and will be presented in the following sections. This includes information regarding public power, history of the town of Boylston and their Light Department, and electric systems including their individual components.

2.1 Power Systems

Power systems are what supply consumers with the power to operate electric appliances and lighting. The basic flow of power is fairly straightforward. Power is generated various locations around the world called power plants. The power is then transmitted at extremely high voltages to transmission stations. The voltage is then stepped down at a distribution substation and again during the distribution to the consumer. Figure 1 is a picture of a typical power system setup.

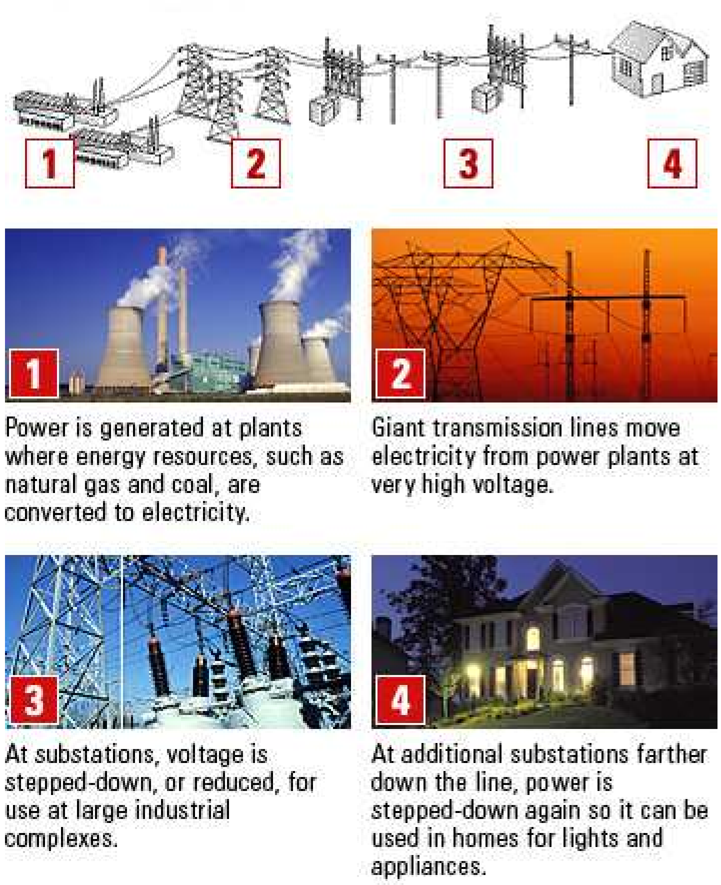


Figure 1: Today's Power System Structure (Alabama Power)

2.1.1 Power System Infrastructure

The description given in the Introduction to Power Systems section is a broad overview of power systems. This section will provide an in depth description of the power plant, transmission and distribution stages using the flow chart in Figure 2.

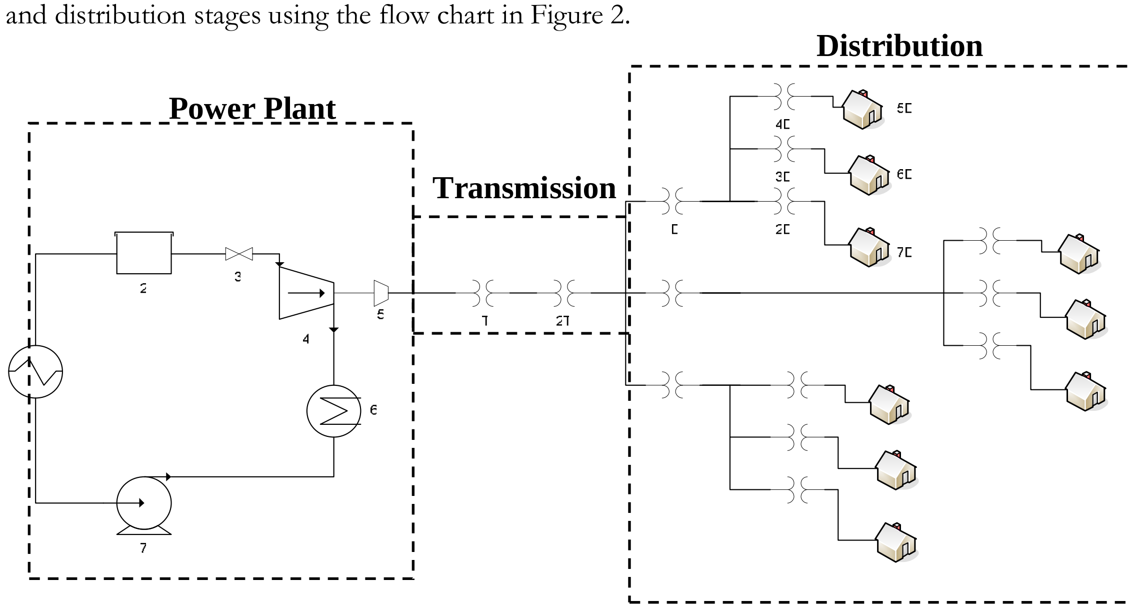


Figure 2: Schematic of Power Infrastructure

The power plant is the first stage where power is generated. The power plant stage can be further separated into the following components (1) boiler (2) vessel (3) valve (4) turbine (5) alternator (6) condenser and (7) pump. The boiler increases the temperature of fossil fuels such as gas, oil or coil to create steam. The steam is then collected at very high pressures in the vessel. The vessel releases the steam through a valve and into a turbine. The steam turns the blades of the turbine which causes the alternator to produce power at approximately 23 kV. Any excess steam that is not used to turn the turbine is passed into a condenser. The condenser raises the temperature of the steam so that condensation occurs. A pump is then used to send the liquid back to the boiler so that it may be recycled and used again in this process.

The transmission stage takes the power generated at the power plant and sends it via transmission lines to a step up transformer (1T), located at a transmission station. The step up transformer takes the 23 kV and increases it to approximately 345 kV. This is done so the power can sustain traveling long distances; the longer the distance the more power is lost. When the power is closer to its destination it is sent through a step down transformer (2T). This step down transformer decreases the voltage to approximately 69 kV. The power is then branched off and sent to various distribution substations.

At the distribution substations, the power is sent through another step down transformer (1D). This transformer decreases the value of the voltage from 69 kV to approximately 13.8 kV. The power is split up and sent in different directions in order to cover all of a city or town. The voltage gets decreased once more with another a step down transformer (2D, 3D and 4D). The transformer reduces the voltage from the 13.8 kV to approximately 120/240 volts. The distribution lines then send the power to the industrial, commercial and residential consumers (5D, 6D and 7D) as needed.

2.2 Components of Electrical Infrastructure

A power system consists of several components, mainly transformers, poles, lines, hand-holes, streetlights, fuses and switches. Familiarity with power system equipment helps understand how the electrical energy flows from the alternators to the end users. In this section these major components and their functions will be described.

2.2.1 Transformers

A transformer is "a static device constructed with two or more windings used to transfer alternating current (AC) electric power by electromagnetic induction from one circuit to another at the same frequency but with different values of voltage and current"(Kurtz and Shoemaker 1992).

The transformer is composed of windings, which are separated into two sections the primary and secondary windings. The ratio comparing the number of turns on the primary winding and the number of turns on the secondary winding is called a turn ratio. The turn ratio determines the voltage ratio, the voltage input versus the voltage output of the transformer. For example, the primary winding in Figure 3 is inputting 7,200 volts while the secondary winding is outputting 240 volts; this indicates that the turn ratio for this transformer is 30:1. Figure 3 also depicts a center tap labeled as the ground wire on the secondary, which in this case is cutting the 240 volts secondary into

120 volts sections on either side. Grounding the secondary winding will divide the voltage into two - separate sections; this does not lower the output voltage.

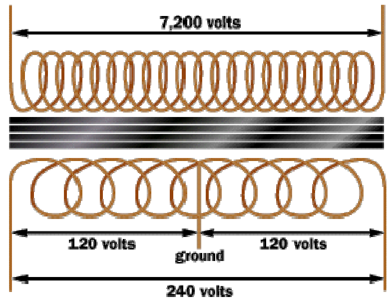


Figure 3: Windings of a Distribution Transformer (Brain 2006)

The turn ratio, as previously described, determines the voltage that is induced on the secondary. Transformers can be used to either step up or step down voltage, making it a very useful component in the power system.

Transformers lose energy mainly through the windings described above and it's core. The core is another basic component of the transformer, traditionally consisting of steel laminations. The purpose of the core is to conduct magnetic flux, which produces voltage while also providing the windings with a structural base. Over the years, research has shown that although the steel transformers have approximately 97% efficiency rating, cores made of newly developed materials, such as amorphous alloy, can produce a nearly perfect efficiency rating (approximately 99%). Amorphous transformers, use amorphous alloy as a core, are an improvement over the traditional steel core transformer because they reduce losses in the core thereby increasing the efficiency of the transformer.

A transformer is not only classified by the turn ratio, material of the core and windings but furthermore by the different types and rating, such as kVA and impedance. Different types of transformers include pole-type, pad-mount, submersible and direct-buried. However, two types are primarily used in an electrical system, the pole type distribution transformer and the pad-mount transformer. The pole type transformers, as suggested by the name, are mounted on the poles of an electrical system. The pad-mount transformers are primarily used for underground systems. They are concealed in a green box structure and have an opening, which allows the underground wires to protrude through the bottom and connect to the transformer. Both pole-type and pad-mount transformers are enclosed in a structure of some kind both for the protection of the component and safety. "The completely self-protected (CSP) transformer includes a lightening arrester, primary fuse and appropriate secondary over-load and short circuit protection" (Adel). While conventional transformers have the arrester and fuse located externally. The CSP transformers are more expensive then the conventional however they reduce installation time, outage time and the amount of damaged components that need to be replaced (ERMCO Components).

The capacity of the transformer is rated using units of kilovolt-amps. Kilovolt-amperes commonly referred to as kVA is the measure in thousands of volts of apparent power in a transformer. The higher the kVA, the larger the load capacity the transformer is capable of. The impedance rating of the transformer refers to the resistance across the windings. The diameter and insulation of the wire used for the winding also limit the maximum voltage and current for the transformer (Integrated Publishing). The life span of a transformer can range from 20-30 years, maybe more depending on load of the unit (Copper Development Association). When deciding which transformer is best equipped for any given situation, it is important to keep all these ratings discussed in mind.

2.2.2 Poles

Poles are the structures that provides support for the lines, and provides housing for the pole mount transformers as seen in Figure 4.

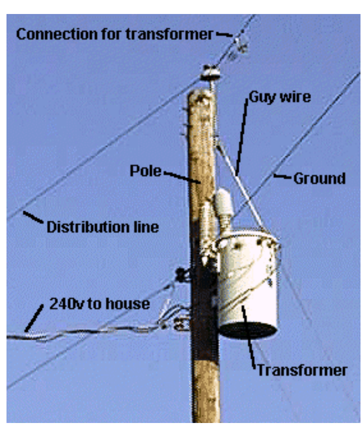


Figure 4: Typical Electric Pole and its Components (Brain 2006)

There are many types of poles, for instance there are wood poles, reinforced-concrete poles, steel poles, steel towers and aluminum towers. The most common pole type is the wood pole because it is the most economical. Wood poles are made of different wood types; the most frequently used are the southern yellow pine, western red cedar, Douglas fir, and western larch. The type of wood used is important because the price and rate of deterioration for each type varies. To extend the life of the wood, a preservative treatment is applied to the pole as specified by the American Wood Preservers' Association. More recently, the wood resources have depleted and solid wood poles are becoming harder to come across making them more expensive.

An alternative to the wood pole are the laminated wood poles which are made by gluing layers of composite wood together by pressure(Kurtz and Shoemaker 1992). As of now the laminated poles are more expensive than solid wood poles but they are also lighter, smooth, clean, have satisfactory dialectic strength and use much less wood. In most systems the solid wood poles are still the most common, however if their prices keep rising, laminated wood poles will be a more economical alternative.

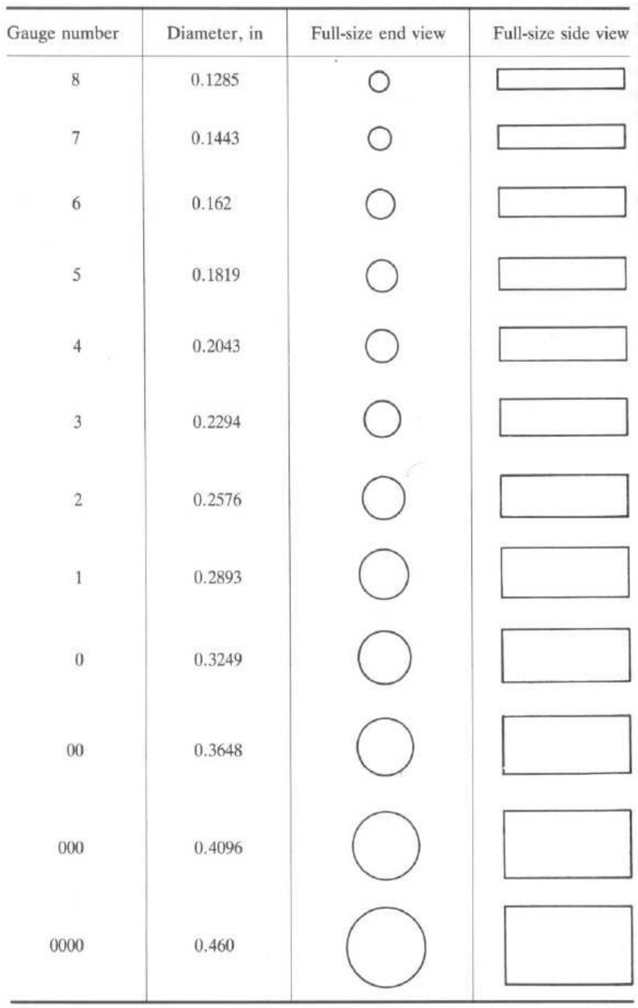
Poles are classified by their different attributes, length, top circumference and circumference measured 6ft from the butt end. The American National Standards Institute (ANSI) regulates the attributes of a pole as follows: the length of a pole starts at 25ft and can be incremented by 5ft steps; the minimum top circumference of the pole is 15in and can be incremented in 2in steps; and the circumference measured 6ft from the butt end determines to which class number (1-10) a pole is given based on the length and circumference of the pole. This classification determines strength to resist loads applied 2ft from the top end of the pole (Kurtz and Shoemaker 1992).

Each pole is equipped with fiberglass insulator support brackets for the lines. There are multiple construction types (wishbone, armless, cross-arm etc.) and multiple poles are often times combined together to create larger structures (i.e. H-frame structures). Although many think of the poles as just a piece of wood, it is clearly the backbone of the system.

2.2.3 Lines

Line conductors, which allow for the flow of electrons, are the carriers of electricity from the power plant to the consumer. Lines are composed of metals that are classified by two major characteristics, conductivity and tensile strength. The metals seen most often in power lines are copper, aluminum, steel, or a combination of copper and steel, or aluminum and steel. Copper is commonly used for its high conductivity and high tensile strength. Copper has its faults as well; it is heavy and susceptible to heat. The tensile strength of copper is decreased when its temperature is increased. Aluminum rates lower in both conductivity and tensile strength when compared to copper. To achieve the same conductivity as a piece of copper, the aluminum must have a 1.66 times larger cross sectional area. The tensile strength is proportional to the area, therefore as the area increases the tensile strength does as well. Aluminum is also a lighter alternative to copper and is better used for long spans. "Conductors are classified as solid or stranded. A solid conductor is a single conductor of solid circular section. A stranded conductor is composed of a group of wires made into a single conductor." (Kurtz and Shoemaker 1992). When stranded aluminum is used, a steel core is used to help with tensile strength, which is more effective for long spans. The name for this type of line conductor is aluminum-conductor steel reinforced (ACSR). Steel conductors alone are high in tensile strength and low in conductivity. To make steel a more efficient conductor, steel is welded together with either copper or aluminum to make copperweld steel conductors or alumoweld conductors, respectively (Kurtz and Shoemaker 1992).

The gauge, along with the metal type of a line conductor helps determines the load and the span that a given line is able to withstand. The American wire gauge uses a range of numbers to establish the diameter of the conductor. As the gauge number increases, the diameter decreases as can be seen in Figure 5. "An increase of 10 in the gauge number increases the resistance 10 times and cuts the weight and cross section into one-tenth" (Kurtz and Shoemaker 1992).



Gauge number	Diameter, in	Full-size end view	Full-size side view
8	0.1285		
7	0.1443		
6	0.162		
5	0.1819		
4	0.2043		
3	0.2294		
2	0.2576		
1	0.2893		
0	0.3249		
00	0.3648		
000	0.4096		
0000	0.460		

Figure 5: American Standard Wire Gauges (Kurtz and Shoemaker 1992)

There are 3 main types of lines used on the higher voltage lines or the primary lines, the 336 MCM, 4/O and 3/O. The 336 MCM is the largest gauge and 3/O is the smallest gauge of the three. These line types are commonly made of aluminum and have a smaller gauge, which as shown in Figure 5 indicates that the lines have a larger diameter.

2.2.4 Handholes

Handholes can be found in underground systems and are smaller versions of a manhole. Handholes are used when small splicing chambers are necessary and are sometimes called splice boxes. The cable the is housed by the handhole makes a complete loop inside the box, and for this reason they should be restricted to one conductor cable, as seen in Figure 6. The handhole should also be able to withstand any load that is likely to come across it and all weather conditions. Since handholes are placed beneath the ground they should remain flush with its surroundings (sidewalk, pavement or grass).

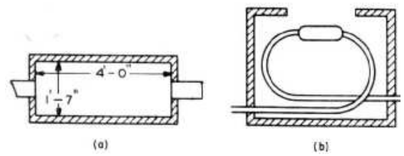


Figure 6: Distribution Handhole with Recommended Dimensions Shown. (a) Plain view; (b) elevation (Kurtz and Shoemaker 1992)

The American National Standard Institute on Underground Enclosure Integrity specifies the size, wire entry, and covers of handholes. ANSI also states that handholes without bottoms should enclose wiring that is suitable for wet conditions (Stephens 2003). The most common materials used in the construction of handholes are concrete, polyester resin, polymer, and fiber glass. Companies that produce handholes are moving away from concrete to polymer and fiber glass because they are lightweight and easy to install. The following picture in Figure 7 depicts a handhole that is polyester resin and reinforced by fiber glass, sold by Electri-Glass Inc.

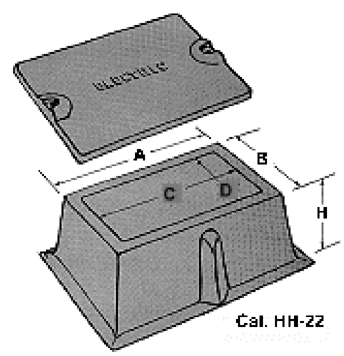


Figure 7: Example of a Fiberglass Handhole Sold by Electri-Glass Inc. (Electri-Glass)

2.2.5 Switches

Switches used in power systems are high voltage switches that are controlled remotely or manually with a hot-line tool called a switch stick. Switches are used to connect or disconnect a circuit that is energized. Switches are categorized into four common classes(Kurtz and Shoemaker 1992):

1) **Air Switches**
   a) Circuit breaker
   b) Air break
   c) Disconnect
2) **Oil Switches**
   a) Oil circuit breaker
   b) Oil circuit recloser
      i) Sectionalizer
3) **Vacuum Switches**
   a) Vacuum circuit breaker
   b) Vacuum recloser
4) **Sulfur Hexafluoride Gas (SF_6) Switches**
   a) Circuit breaker
   b) Circuit switcher
   c) Recloser

"A circuit breaker is a device used to complete, maintain and interrupt currents flowing in a circuit under normal or faulted conditions"(Kurtz and Shoemaker 1992). Circuit breakers protect against overloads, short circuits etc., they differ in what mechanism (mechanical, hydraulic or pneumatic) that control the contacts and in what is used as an arc-interrupting medium (air, oil, vacuum or sulfur hexafluoride gas). Reclosers can be oil vacuum or sulfur hexafluoride gas and are similar to circuit breakers. They are designed to interrupt and reclose an AC circuit automatically in case of a fault. Sectionalizars, which are oil switches, work with reclosers to isolate a fault in the lines. Switches play an important role in the power system because they allow for the isolation of a problematic situation.

2.2.6 Fuses

Fuses are used as an inexpensive way to protect a portion of the electric system. They are designed to create an open circuit when there is an irregularity in the circuit, such as a short or overload. Fuses are made of tin, silver, lead, copper or an alloy such as tin-lead. These materials melt when kept at a certain temperature for a specified amount of time, also known as blowing a fuse. The temperature of the metal increases based on the amount of current flowing through the materials, the more current flowing the hotter the material gets. Fuses are placed in enclosures so that molten metal can be contained. There are two main types of fuses, low-voltage and high-voltage fuses. The low-voltage fuse is the plug or cartridge type. The high-voltage fuse is used on the distribution system and can be expulsion, open-link, current-limiting, liquid or boric acid types. Figure 8 depicts an elementary distribution system that utilizes fuses. The purpose of the fault in Figure 8, denoted by an X, is to see how one would be contained in an actual system. The fault, meaning an overload or short circuit, would be contained by disconnecting a section of the system. The fuse (E) allows for the faulted section to be disconnected and still have the rest of the system functioning normally, thus minimizing the size of the problem.

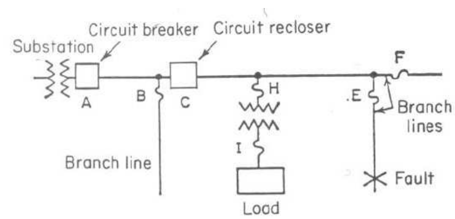


Figure 8: One-line diagram of an elementary distribution system. Over-current protective devices are shown as A (circuit breaker), B (fuse), C (circuit recloser), E, F, H and I. Fault is shown as X. Device E should disconnect the branch line and permit the remainder of the system to operate. (Kurtz and Shoemaker 1992)

2.2.7 Consumer Connections

There are two basic configurations for industrial, commercial and residential consumer connections. These configurations are overhead systems and underground systems. Figure 9 is an overhead system that can be broken down into (National Grid 2005)**:**

1. Distribution Lines that run from the utility pole to the consumer
2. Weather-head and Insulator at the point where distribution lines connect to consumer's building.
3. Service Entrance Cable is the wire that runs from the weather-head to the electric meter and from the electric meter to the service panel.
4. Meter Box on which the electric meter is mounted.
5. Electric Meter which measures the amount of electricity used in kilowatt-hours.
6. Main Service Panel which includes the fuse boxes and/or circuit breakers.

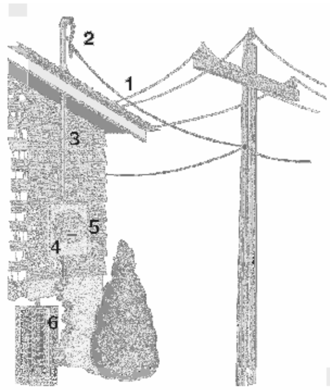


Figure 9: Consumer Connection to an Overhead Setup (National Grid 2005)

The underground system as shown in Figure 10 contains (National Grid 2005)**:**

A. <u>Underground Service Entrance Cable</u> which runs underground from a transformer to the electric meter and from the meter to the main service panel.
B. <u>Meter Box</u> on which the electric meter is mounted.
C. <u>Electric Meter</u> which measures the use of electricity in kilowatt-hours.
D. <u>Main Service Panel</u> which includes the fuse box and/or circuit breakers.

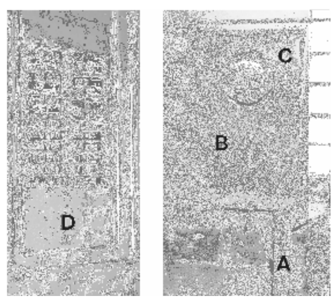


Figure 10: Consumer Connection for an Underground Setup (National Grid 2005)

The electric company takes responsibility only for the distribution lines and the meter itself. The consumer is responsible for the upkeep and repair of all other components. In the end, the meter provides the electric company with the numerical amount of kilowatt-hours used and the electric company then bills the consumer based on the reading.

2.2.8 Streetlights

In the seventeenth and eighteenth centuries, candlelight and gas lighting were used primarily to light the streets. By introducing the incandescent lamp, Thomas Edison made a great improvement in street lighting. Modern lamps are electric discharge lamps, which allow electrons to flow between electrodes through an ionized gas or vapor (i.e. mercury vapor, metal halide, low-pressure sodium, high-pressure sodium and fluorescent). The most common lamps used in newer streetlight systems are high-pressured sodium due to the fact that they output more light per watt of electric power then other types. The streetlight fixture varies in length depending on its location, and is connected onto a pole. In the case of an underground system, it is affixed to an ornamental pole or post which has a hollow center for wiring. The voltage that supplies the streetlights is provided by the line-voltage supply. Refractors are placed over the lamp to control the distribution of light (Kurtz and Shoemaker 1992).

Streetlights are only needed in the darkness, in order to have them operate only when dark, some sort of timing device is necessary. There are different devices used to control the timing of the streetlights. An automatic clock control switch is used to automatically turn the lights on or off depending on the time of day. These automatic clock controlled switches can be motor or spring driven. Photoelectric-cell control relays use photocells, a variable resister whose resistance depends on the amount of light detected, to detect the level of light. Once the light reaches a particular magnitude, the relay will turn on or off. This system works adequately because the lights are then used during bad weather or cloudy days when it may be needed. Cadmium-sulfide-cell controlled switch is another device used for the timing of streetlights. Similarly to the photocell, the cadmium-sulfide cell varies resistance depending on light detection, switching on when there is high resistance and off when there is a low resistance. Streetlights create safer surroundings, however in extremely lit areas light pollution may be a problem.

2.3 History of Boylston Municipal Light

The town of Boylston, like most towns, started off relatively small and grew as time progressed. The population has fluctuated as result of building railroads, mills, reservoirs and highways (I-290 and Rt-495). The chart in Figure 11 plots the town's population throughout the years, which shows a steady increase after about 1920 (See Appendix A for more information on the history of Boylston) (Dupuis 1972; Dupuis 1972).

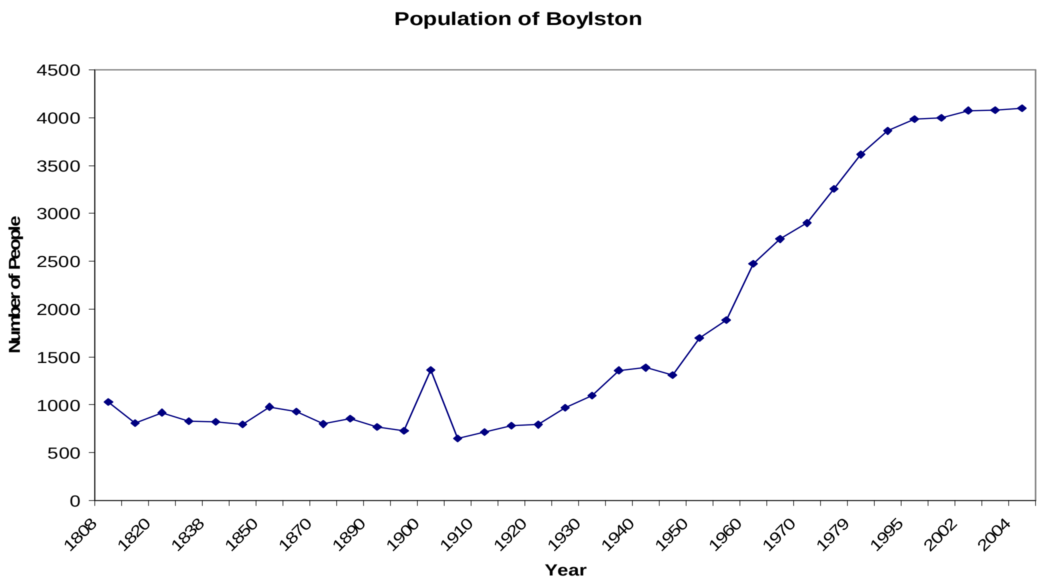


Figure 11: Population Growth for Boylston

As the population continued to increase the town expended to its present boundaries, with a population of approximately 4,100 residents. With the developments in electricity becoming increasingly popular and Boylston's population rising, there was a need for a light department within the town.

Article 23 of the warrant for Boylston's March 6, 1911 town meeting proposed, that a committee be formed for the "Investigation of the matter of lighting the streets and buildings of the town with electricity." (Anonymous1912) The article was voted on and passed and the meeting moderator promptly appointed a committee of three members. The original proposed plant size included a two-circuit system of four and one-fifth miles of line and 40 streetlights. The Committee identified both the Connecticut River Transmission Company and the Worcester Electric Light Company as possible sources of current; both of these choices would require lines being built to the Boylston, West Boylston or Boylston, Shrewsbury town lines.

The initial report, no matter how thorough it seemed, was not passed during the March 27, 1911 meeting but two hundred dollars was appropriated to the committee to further its work. Returning to the town meeting agenda on May 15, 1911 the Electric Lighting Committee now working along side of the Selectman of the Town of Boylston presented a further report. The town would be able to purchase electricity at the cost of three cents per kilowatt. This power could then be sold to the town's families at twelve cents per kilowatt; compared to bordering towns already owning electrical system this was a bargain price for the time. Additionally, it would cost the town $87.40 to provide power to a system of forty streetlights. It was further investigated by the committee that a worker could be hired at the rate of $15 a month to care for the system (Boylston Town Report of 1912).

The voting members were reserved in accepting the proposition, knowing initially the electric light plant would not be earning a profit, but rather it would cost the Town of Boylston $600 a year to run. Eventually, after a series of non-majority votes the motion was pasted and $1,500 was provided by the Boylston Treasury in the form of repayable notes for the construction of a substation and four miles of line to feed initially fifteen meters for customer hook-ups. Additional money was also granted by the selectman and borrowed from the People's Savings Bank to be repaid at a later date. The twenty customers of 1912 quickly grew to thirty-seven by the end of 1913; and has consistently grown ever since. A good representation of the growth in Boylston's electric system is the rise in peak demand in power over the years rather than by shear number of customers alone.

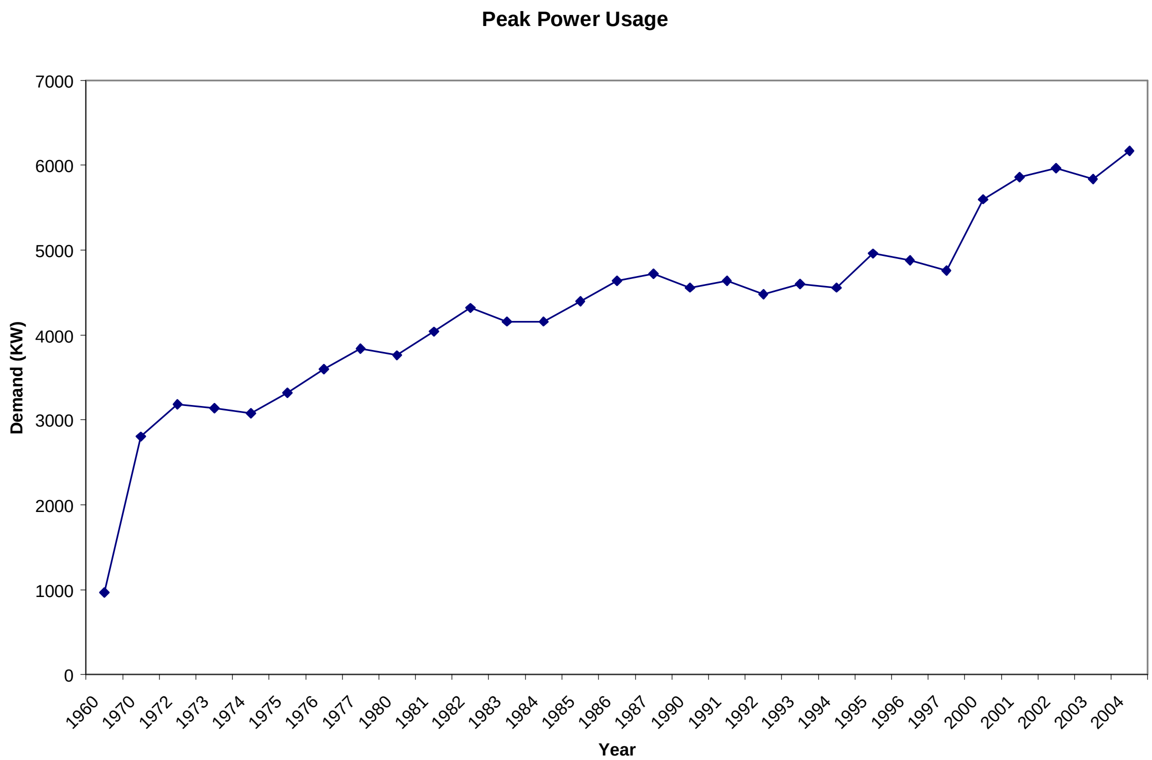


Figure 12: The peak demand on Boylston's municipally owned electric system has grown steadily since its creation in 1912 when demand was below 10 kilowatts.

During the proceedings of the March 3, 1913 town meeting it was accepted that a three person Municipal Light Board be elected to oversee all decisions and actions involving the light company. This elected board operates separate from the town and is still in place today. The term of a Municipal Light Board member is three years and an election for a new member is held every year, though many members over the years have served numerous consecutive terms.

Presently the Boylston Municipal Light Department consists of six employees and still a three member lighting board. The lighting board members oversee the finances and executive decisions of the department; while the employees oversee the daily organization and maintenance within the electrical system. Three linemen work in the field trimming trees and making repairs on the lines, transformers, and poles; while two secretaries work in the office processing the billing of customers, while one manager oversees all aspects.

Looking back it can be concluded that the Boylston Municipal Light Department has been effective in providing its consumers with reasonably priced electrical energy. It is important as a semi-public company that they are make appropriate decisions for the good of its customers. These decisions include making upgrades of the system as needed to prevent outages and updating contracts in order to provide the cheapest electricity available. It is inevitable that the price of electricity will have peaks due to outside influences yet overall the cost of electricity in Boylston, when adjusted for inflation, has been stable for the last thirty years.

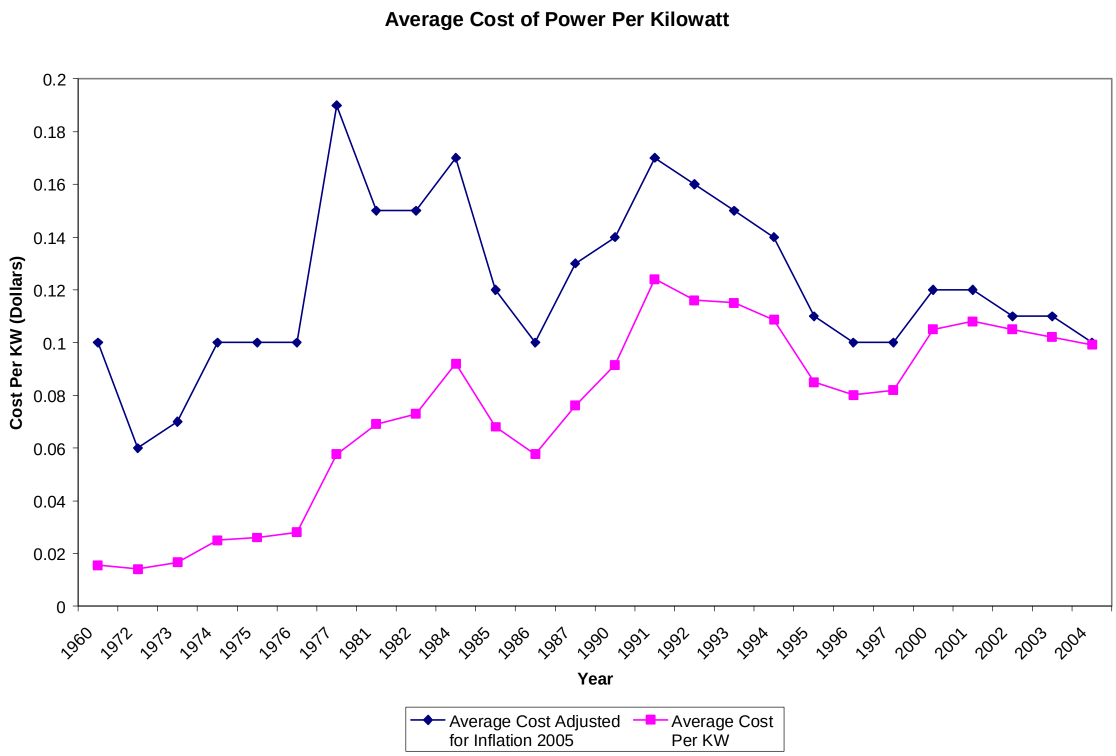


Figure 13: The average cost of power has fluctuated over time, yet when adjusted for inflation the average cost per kilowatt in 2004 and 1970 is equal.

2.4 Public Management of Electric Infrastructures

The uses of electricity are constantly increasing and these upward trends show no signs of breaking. There are both publicly and privately owned electricity, but this paper will only discuss publicly owned companies as it pertains to our discussion. Publicly owned power is a backbone resource of society that can be provided while keeping the flow of money strongly planted in the best interest of the community, rather then in the pockets of investors. The term “public power” gives reference to an electric utility system that is owned and operated within the community (American Public Power Association 2006).

Today, there are over 2,000 cities and towns that receive their electricity from publicly owned and operated organizations (American Public Power Association 2006). These organizations have some benefits over privately owned companies. While providing power that is cheaper to the local consumer, public power also creates more jobs in the community, and long-term alliances with the goals of municipal government. The leaders of any electrical system must be aware of the needs of the customer and provide adequate customer support to gain their loyalty. When the leaders and workers reside in the municipality this level of support and loyalty is greatly strengthened (American Public Power Association 2002). A history of loyalty will get you customers, but it is system reliability that will keep customers from seeking alternative energy sources.

"In an industrialized society, roughly 10 percent of the people are leaders in the community. They contribute to the creation of jobs and improving living standards."(Vennard 1979, 403) When managing a power system a great deal of dedication to the customer is needed, for without customers business would be nonexistent. To the average consumer good management means their lights turn on when they come home at night, and at the end of the month their bill is low. Power systems, whether public or private, need to be staffed in such a way to receive results. Once the management is chosen, certain tasks need to be executed to maintain an efficient up-to-date infrastructure.

The power system will need to be constantly monitored for its functionality, and wear and tear on its components. Plans need to be made and frequently reviewed for both immediate and long-term upgrade schedules (Vennard 1979, 403). A good manager will not only have to assess and circumvent problems are they happen; but also predict and improve future problem areas before failure occurs. Prediction also leads to knowing the appropriate time to upgrade the distribution and generation systems to handle increase in demand. Often large upgrade projects will take years to complete, and need to begin with enough time to prevent unreliable service.

The largest amounts of money managed in an electrical system are not for the distribution system but rather for the generation system or purchasing of energy from outside contracts. The power system is always growing and levels of demand are changing, good management needs to have solid forecasting on the amount of energy that will be needed for any given time period. With planning power for certain days and months can be purchased ahead of time at lower costs and these savings can them be passed down to the customer. It is in situations, such as on a hot summer day, when not enough energy is bought that the manager must then purchase power at high market prices, quickly decreasing profits. It is a classic economical scenario of supply and demand, when power is needed the most it will cost the most.

2.4.1 Management of Boylston Municipal Light

Now that general electric infrastructure management is understood, this next section will focus on the specific management of the Boylston Light Department. As previously stated, it is comprised of a manager, three linemen, and two secretaries. Three elected officials make up an electrical board that ensures the Light Department acts in the best interest of the town and its customers. A flowchart of the responsibilities of the Light Department can be seen below.

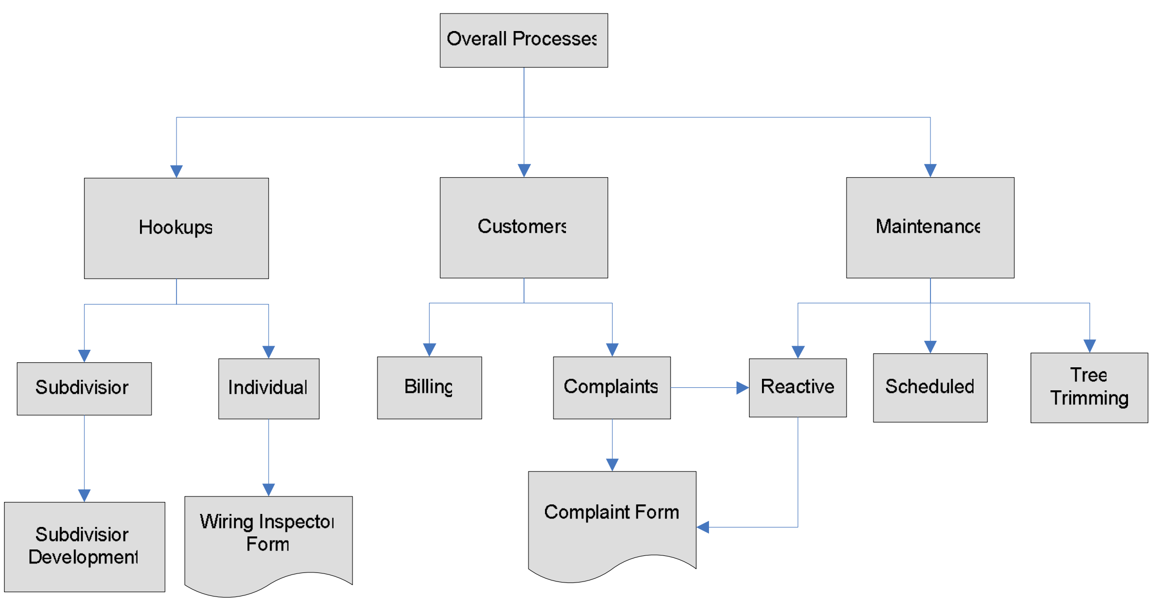
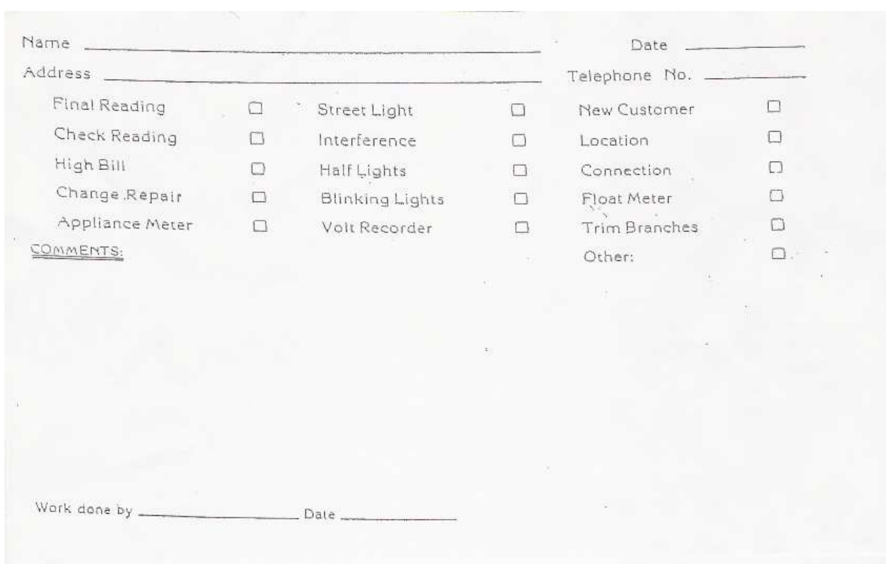


Figure 14: Flowchart of the Management Process of Boylston

The Light Department is also responsible for buying and providing power to the town of Boylston. The power is purchased from the Massachusetts Municipal Wholesale Electric Company. MMWEC buys its power from many different sources and relays it to smaller companies through individual contracts previously set up. The only time that power is not transferred at a previously agreed price is when it is bought on the open market. This happens when actual power usages exceeds expected usage, and results in vast an increase in price per kilowatt-hour.

2.4.2 Current Forms

The Boylston Light Department currently uses two main forms. The first one is for recording complaints or problems that customers have. This form can either be filled out by a secretary hearing a problem over the phone, or by a customer that comes into the office. There are spots for fifteen different problems, as well as a place to write in a problem that is not listed. Also, the customer's information is recorded, along with the name of the lineman that did the work to solve the problem. This form can be seen below in Figure 15.


Name ____________ Date ________
Address ____________ Telephone No. ________

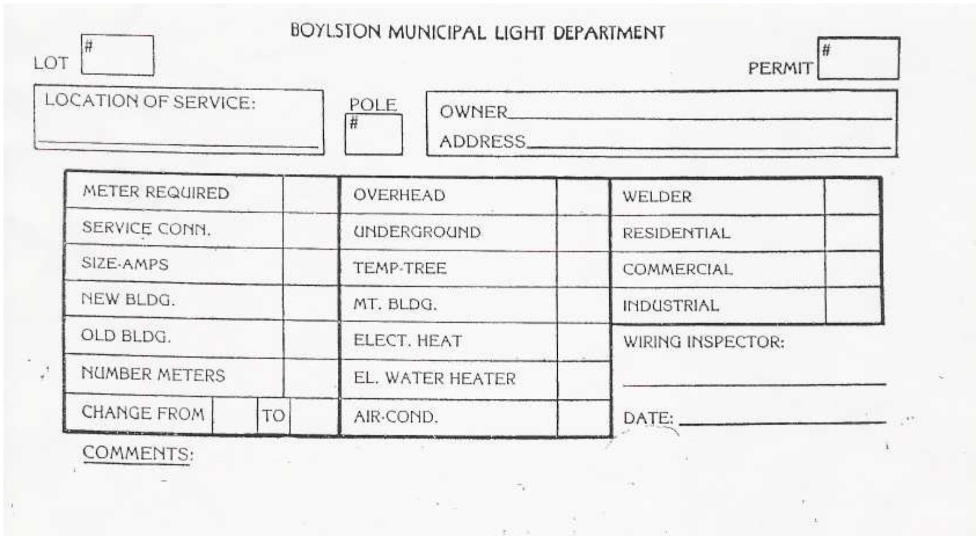
Final Reading	☐	Street Light	☐	New Customer	☐
Check Reading	☐	Interference	☐	Location	☐
High Bill	☐	Half Lights	☐	Connection	☐
Change Repair	☐	Blinking Lights	☐	Float Meter	☐
Appliance Meter	☐	Volt Recorder	☐	Trim Branches	☐
				Other:	☐

COMMENTS:

Work done by ____________ Date ________

Figure 15: Existing Complaint Form

The next form is one used by the town wiring inspector to document the electrical situation at a residence. This form is filled out after electrical service is brought to a house, when the wiring inspector performs his inspection. Once the form is filled out, it is given to the Light Department so they can record information for the residence, such as; whether it is residential or commercial or whether or not it has electric heat. Upon receiving the form, the Light Department extracts the necessary information and files the form away. This form can be seen in Figure 16 below.



BOYLSTON MUNICIPAL LIGHT DEPARTMENT

LOT #

PERMIT #

LOCATION OF SERVICE:

POLE #

OWNER

ADDRESS

METER REQUIRED		OVERHEAD		WELDER	
SERVICE CONN.		UNDERGROUND		RESIDENTIAL	
SIZE-AMPS		TEMP-TREE		COMMERCIAL	
NEW BLDG.		MT. BLDG.		INDUSTRIAL	
OLD BLDG.		ELECT. HEAT		WIRING INSPECTOR:	
NUMBER METERS		EL. WATER HEATER			
CHANGE FROM	TO	AIR-COND.		DATE:	

COMMENTS:

Figure 16: Existing Wiring Inspector Form

2.4.3 Light Department Involvement in Subdivision Development

After analyzing the processes of the Light Department it became evident that the greatest amount of new data is created when a new subdivision is created. Many new components and hook-ups are added to the system when subdivisions are built. Currently, the electrical systems found in subdivisions are sketched by hand on maps that are filed at the Light Department. A detailed analysis of their process for new subdivisions yielded a flowchart, which can be seen in Figure 17.

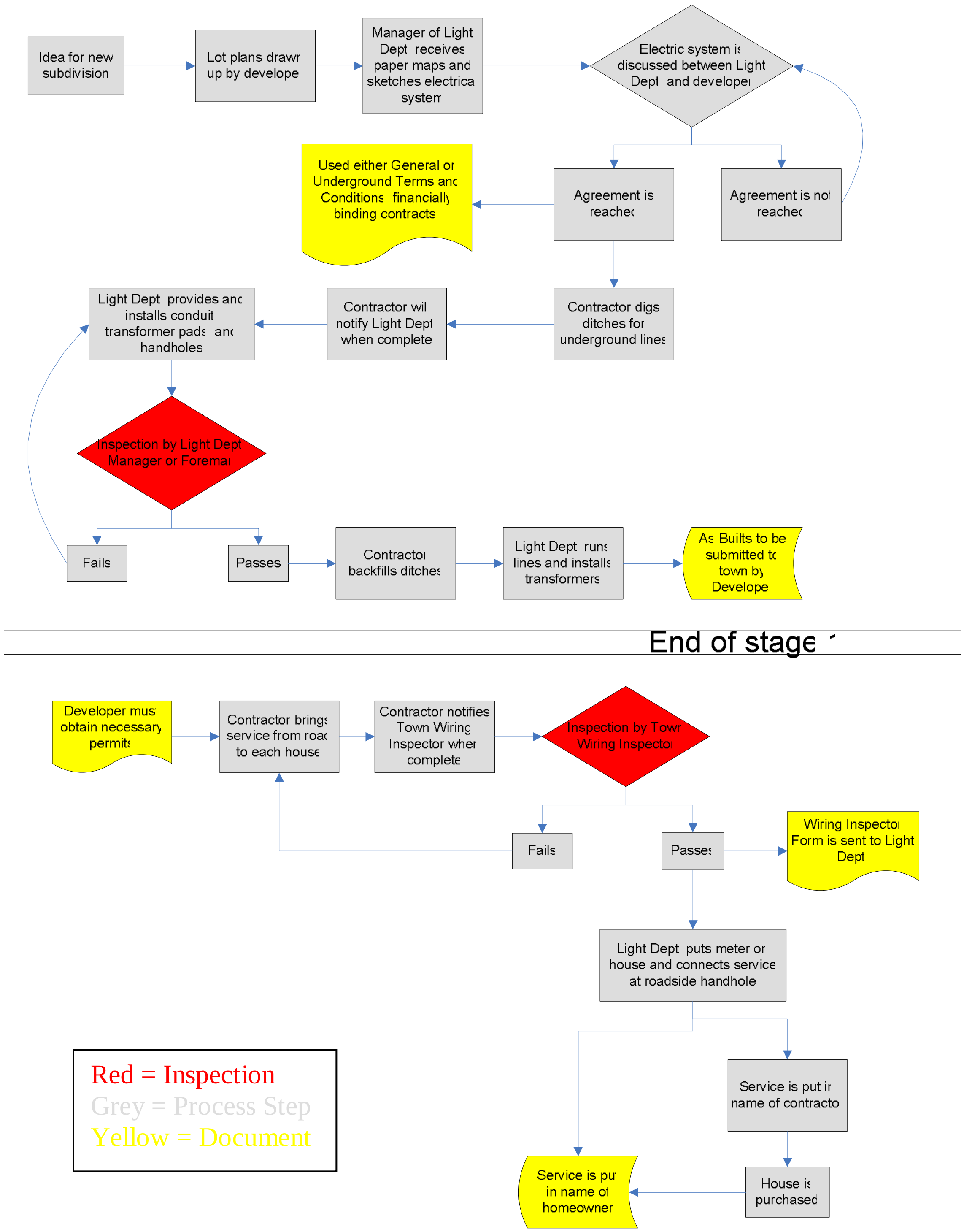


Figure 17: Flowchart of Old & New process

This entire process takes place once the definitive plan of the subdivision is established. Also, the only rules governing the process are found in a Terms & Conditions form that is a binding contract between the contractor and the Light Department. Lastly, no bonds are used in this process, due to the fact that the Light Department is paid upfront by the developer for the work that they will do.

2.4.4 Public Electric Utility Societies

There are many non-profit organizations at both the state and national levels looking out to provide financial and research support in the area of public power. Such activist groups include: The American Public Power Association (APPA), The Large Public Power Council (LPPC), and the Massachusetts Municipal Wholesale Electric Company (MMWEC). Unlike the corporate world of power, such advocacy organizations are mainly focused on providing the cheapest power possible to the customer through competition and harmony in the economy; due to the presence of public power companies. Undoubtedly in the coming years the topic of energy will be one of great debate, and small municipal power companies will need these organizations with legislative power in order to come out on top.

2.5 Build Out Analysis

"On January 21, 2000, Governor Paul Cellucci and Lt. Governor Jane Swift issued Executive Order 418 (EO 418), a measure designed to help communities plan for new housing opportunities while balancing economic development, transportation infrastructure improvements and open space preservation." In layman's terms, the EO 418 is used to find out what developments need to be completed, how to go about getting them done and to prioritize these new developments. There are four main sections in the development plan: housing, open space and resource protection, economic development and transportation.

When looking into these development plans, the population, density, geographical size, natural resources and infrastructure of the present and future community need to be taken into consideration. To do this a build-out analysis of the community is created to show the maximum development permissible under existing zoning regulations and resource protection bylaws. In other words, the build-out maps show the community with all available land occupied by new developments. This allows the community to reevaluate their services and land while also looking at its resources to determine if at maximum population, they would sustain the demands on public services and consumption of resources.

At this time the population of Boylston is 4,200. The Boylston Municipal Light Department currently supplies 2,100 residential, industrial and commercial customers with electricity. The maximum peak of the entire system is 7,308 kW. The maximum peak per customer is 3.48 kW, which occurs at approximately 7 p.m. The Light Department substation, which is jointly owned by both Boylston and West Boylston, is able to supply 24 MW to the town of Boylston; therefore as of now the Light Dept. is nowhere near its max. The End of the Year Report 2006 of the Boylston Light Department provided the numbers in this section.

3 Methodology

The overall purpose of this project is to help the Town of Boylston's Municipal Light Department to improve its record keeping processes, so the department will be able to manage and maintain the existing electrical system and better understand how it is currently working. In order to achieve this goal the following actions were taken:

1. Inventory the components within the system
2. Estimate the cost of updating aging and inefficient components
3. Create an efficient system for keeping the database up to date
4. Investigate future expansion of the system

This project restricted the field of inquiry to public electrical systems and provided a definition of what a public electrical system is and consists of. MapInfo and Microsoft Access software was used to organize the information of the electrical system. The entire electrical system of the town of Boylston, including individual components, was cataloged using the existing maps available. Once the current state of the system was outlined within the database an updating process was designed in order to keep all cataloged data current.

The following sections will provide a more in depth look of the objectives and what was done to accomplish each one. The process used for collecting data on the electrical system will be outlined. The steps taken to create an updatable database will be explained; along with the analyses, recommendations and conclusions that were extracted from the data.

3.1 Inventorying Components

In order to create a database and mapped representation of Boylston's electrical system existing maps and records, as well as personal data collection and observations in the field, must be combined. All of the components will be identified according to the street that they are located on. A preliminary organization effort was taken to create the street identification abbreviations, which can be found in Appendix C. The components are also identified by their position on the street. In most cases logical numbering was used to sequentially number the components from where the main line feeds into the road to the end of the line or road. Once each of the components had an identification street and number, these fields were combined to form a unique identification code. Then, information pertaining to each component was entered into the corresponding database fields. The following sections will discuss and define the information that was entered for each component.

3.1.1 Inventorying Poles

The first step in inventorying poles was to place each one on the map. This was done by creating a new layer in MapInfo and placing it over the orthographic photos. The projection used to create all maps in this project is US State Plane Coordinate Systems; Massachusetts 2001, Mainland Zone (1983, meters), which is optimized for maps of the Massachusetts mainland.

Then, using the maps given to us by the light department, each pole was placed in its approximate location, using streets and buildings as guides. As each pole was placed, using a brown circle as a symbol, its street and sequential number on that street were recorded in the pole browser, or database. This made it possible to give each pole a unique identification code. Once all of the poles were placed, data for each pole was entered, using the paper records provided by the Light Department. The following data fields were used for poles.

- **Pole Number:** Number of the pole on the street, keeping with the numbers previously assigned by the Light Department.
- **Street ID:** The street location of the pole represented by the street code; see Appendix C.
- **Pole ID:** Combination of the pole number and the street code
- **Height:** The height, in feet, of the pole
- **Class:** A number 1 through 7 that specifies the minimum circumference at the top of the pole, in inches
- **Treatment:** Defines the wood treatment given to the pole
- **Year Installed:** Year when the pole was set
- **Joint Owned:** YES if the pole is joint owned by the cable company and the Light Department, NO if it is solely owned by the light department

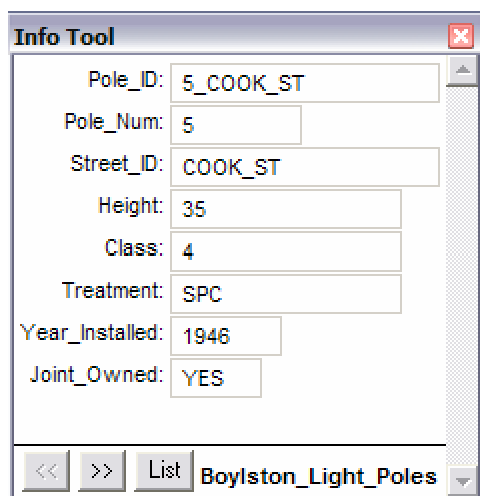


Figure 18: Sample Pole Record

3.1.2 Inventorying Transformers

Once again, the first task for inventorying transformers was to place each one on the map. To do this, a new layer was created in MapInfo and hand drawn maps, given to us by the Light Department, were used to get the location of each transformer. If the transformer was on a pole, its symbol (a green triangle) was placed directly on top of that pole. As each transformer was placed, its street and sequential number on the street were recorded in the transformer browser, or database. This made it possible to give each transformer its unique identification code. The next step was to enter the necessary data for each transformer. This was done using the information on the transformer record cards from the Light Department. The following database entries were made for each transformer

- **Transformer Number:** Number of the transformer on the street, starting at the main streets at the center of the town working towards the boundary
- **Street ID:** The street location of the transformer represented by the street code; see Appendix C.
- **Transformer ID:** Consists of the transformer number and the street code
- **Category Number:** Original catalog number in the Municipal Light Department's paper record system.
- **Pad or Pole:** PAD will denote that the transformer is a pad-mount; usually found as part of an underground system. If the transformer is a pole-mount, then the identification code of the pole it is mounted on will be displayed.
- **Type:** Either CSP (completely self-protected) or Conventional
- **Date Installed:** Date when put into service
- **KVA:** The Kilovolt-Amp rating; a larger number corresponds to a larger transformer
- **Make:** The production company for the unit
- **Serial Number:** Serial Number used to identify the unit
- **Primary Voltage:** Primary Voltage of the line running into the transformer
- **Secondary Voltage:** The voltage of the current coming out of the transformer
- **Phase:** the transformer is Single or 3-Phase
- **Impedance:** The impedance as reported by the manufacturer; this value is given in percent
- **Taps:** If the transformer has adjustable taps, which tap it is on; if not, then NO is displayed
- **Hook-Ups:** Addresses that the transformer services

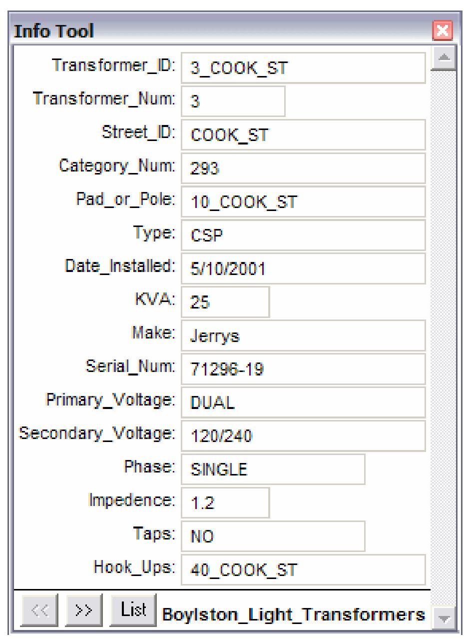


Figure 19: Sample Transformer Record

3.1.3 Inventorying Streetlights

The inventorying of streetlights followed a similar path as the poles and transformers. First there were two new layers created: one for pole mount streetlights, and one for ornamental streetlights. Then, the streetlights were placed on their respective layers, using the symbol of a yellow star. Pole mount streetlights were placed on the same node as the pole they are on, but under the pole layer for aesthetic purposes. Ornamental streetlights are mostly found in underground systems, near a transformer, and were placed in this manner. Once all of the streetlights were placed, data for each one was entered into the respective streetlight browser, or database. The following categories were used.

- **Streetlight Number:** Number of the streetlight on the street, starting at the main streets at the center of the town working towards the boundary
- **Street ID:** The street location of the streetlight represented by the street code; see Appendix C.
- **Streetlight ID:** Consists of the streetlight number and the street code
- **Transformer Location (for Ornamental only):** The Transformer ID for the transformer that feeds the streetlight
- **Pole Location (for Pole Mount only):** The Pole ID for the pole that the streetlight is mounted on
- **Bulb Type:** The type of bulb used in the streetlight, HPS represents High Pressure Sodium
- **Wattage:** The wattage of the bulb

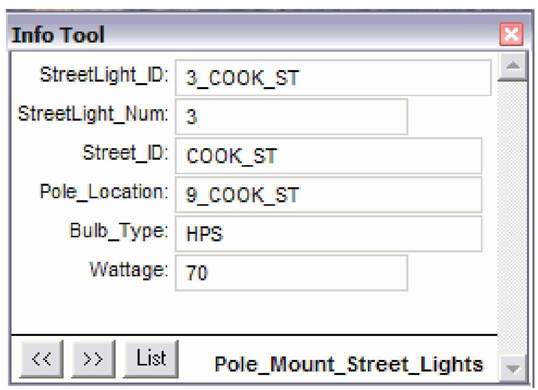


Figure 20: Sample Streetlight Record

3.1.4 Inventorying Handholes

In underground areas where handholes are necessary to provide easy access to electric connections below ground level; handholes will also have to be recorded within our database system. As with all the components they will be referenced and located according to the street they occupy. They will be placed within the MapInfo maps according to the lines that run into the handhole and any notes needed on the purpose of the connections contained by it. As with all components it is good to record the date on which they were put into service as that information becomes available.

3.1.5 Inventorying Fuses

Fuses are an important safety feature within the electric system to prevent damage to other components from the adverse affects of excessive current. Each will be assigned a unique identification code according to the naming scheme described earlier. The most important information to know about fuses is their type and at what current level or temperature are they design to open the circuit to prevent damage. The location and date of installation are key pieces of data for each fuse when it comes to system design and preventative maintenance.

3.1.6 Inventorying Switches

At the present time there are only a few choice switches in Boylston's electrical system, yet by no means does this make them any less important to the system's functionality. The switch will first be named and coded, followed by its location within the town most likely indicated through a pole ID. The type of the switch, for example oil or air-break, is important to identifying its functionality. MapInfo will any notes on the switch's purpose to be attached to the object, whether it is for use during maintenance or to back-up other areas of the municipality during outages.

3.1.7 Inventorying Consumer Connections

When placing the electrical lines that feed houses and other consumer connections, the approximate location on the hook-up on the house will be estimated. In some cases a single building will have multiple electric meters; any of these special cases will be noted along with the buildings address information within the buildings layer. Furthermore depending on the circumstances the lines will be placed on the correct layers in MapInfo depending on whether the secondary lines run underground or overhead to the residence.

3.1.8 Inventorying Lines

Once the poles and buildings are placed inside the MapInfo workspace it is merely a task in connecting the dots in order to draw out the primary and secondary lines. Four layers were created in order to easily separate the overhead primary, overhead secondary, underground primary, and underground secondary line classifications. Extra time was spent placing these lines in separate layers for two key reasons. It will both allow the distinction of secondary and primary lines that run between the same two poles, and simplify the process of analyzing the system later. Then, working layer by layer the appropriate poles, transformers, switches, fuses, and buildings can be connected to finish the electrical system layout. As with previous practices each segment must have a unique identification code, and other quantitative information, which will be organized in the following database entries.

- **Segment Number:** The number of the segment within the street
- **Street ID:** The street location of the line represented by the street code; see Appendix C.
- **Segment ID:** Combination of the segment number and street ID separated by an underscore
- **Feeder:** The feeder the segment belongs to, 1 is for the northern circuit, 2 is for the southern
- **Line Type:** The type of cable used in the segment (i.e. Tree Wire, Copper)
- **Date of Installation:** The date when the segment was put into service.
- **Gauge:** Represents the size of the conductor
- **Segment Length:** Length of the segment, in feet

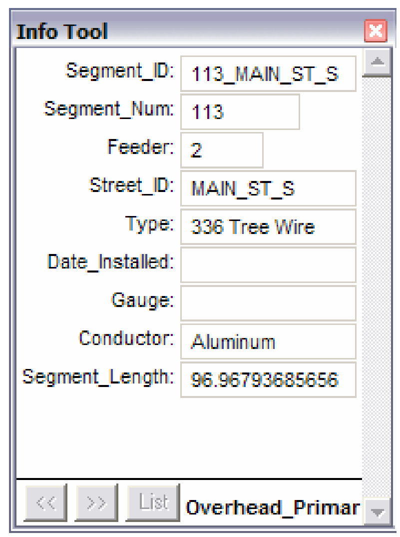


Figure 21 Sample Line Record

3.2 *Estimating Costs for Infrastructure Upgrades*

One type of analysis that was conducted on Boylston's electrical system is looking at costs for upgrading certain components. The system contains parts that are not up to date, causing electrical losses and compromises to safety. Both of these have negative effects on the residents of Boylston. Electrical losses drive up the cost of energy, putting an added burden on the townspeople. Also, unsafe electrical equipment can make the town a dangerous place to live and raise a family. All of these factors work together to show that out of date electrical components have adverse affects on the entire community.

Some of the obsolete components that will be analyzed are transformers, lines, and poles. By taking the time and money to replace these aging components the efficiency and reliability of the system in the future will be greatly increased. This is where decisions will need to be made by Boylston's Municipal Light Board as to whether these expensed now will pay off in the long run.

An age cutoff will be chosen for the poles and transformers, over which replacement will be recommend and priced in order to increase the dependability of Boylston's Electrical system. These costs will be determined using current market prices for new components assuming identical parts will be used for replacement. In the case of electrical line upgrades costs will be estimated on a per foot basis; it will be our recommendation to homogenize the main high voltage feeders to the same line size and we will later estimate this cost. Current market prices as received by Gary Harrington, Municipal Light Department Manager can be found in the table in Figure 22.

ITEM	UNIT MEASURE	PRICE
25 ft Pole	EA	$130.00
30 ft Pole	EA	$155.00
35 ft Pole	EA	$209.00
40 ft Pole	EA	$285.00
5-10 kVA Transformer	EA	$800.00
15 kVA Transformer	EA	$1000.00
25 kVA Transformer	EA	$1200.00
37.5 kVA Transformer	EA	$1400.00
336 mCm Aluminum Tree Wire	FT	$1.86
4/0 Aluminum Tree Wire	FT	$1.86
3/0 Aluminum Tree Wire	FT	$1.79

Figure 22: Unit Replacement Costs

3.3 Designing a System for Information Upkeep

Once the mapping and data entry are finished, and the project is completed, it will be up to the Light Department to keep the entire system current. It is necessary as part of this project to come up with a way to facilitate this changeover of data. First, the current processes and forms used by the Department were analyzed. This showed how they are currently keeping records, and where they lack organization and efficiency. One main problem with the current forms is that they are filed as paper copies, which take up much space and make it difficult to organize them. The solution was to create new forms that can be filled in and filed electronically. This will enable secretaries at the Light Department to easily pull up a form whenever they need it. It will also give them the capability of exporting the data from all of the forms to one spreadsheet. This will allow for several different types of analysis, such as counting the number of a certain problems in the past year, or viewing the number of new residential buildings constructed in the past six months. Both of these would currently require the secretary to count through stacks of forms, but will now be capable with the click of a mouse.

The other part of this objective is to create an example of the end product of the system. This includes a demonstration about how customers and Light Department employees will be able to interact with the database and forms in the future. This is a vital part of the project, as it puts together all of the pieces that were worked on. When designing this system the needs of the Light Department and customers were be taken into consideration. It is important to note, however, that this is only a mock up of what the system will look like once the proper software is developed to make it a reality.

3.4 Demonstrating Additional Analytical Capabilities

This section uses the build out of Executive Order 418 described in the background section 2.5 to analyze the Boylston Municipal Light Department's system of the future. The main interest of concern is to see if the system will be able to support its customers at full expansion.

3.4.1 Analyzing System Capacity

Currently, the town of Boylston does not include the electrical system in their build-out analysis. We plan to create one for the electrical system based on the present build-out conditions and numbers reported by the Central Mass Regional Planning Commission (CMRPC) as of 2006. With this analysis, Boylston will be able to discover whether or not their system can withstand the maximum build-out conditions. The process of this build out analysis follows the flowchart found in Figure 23 below.

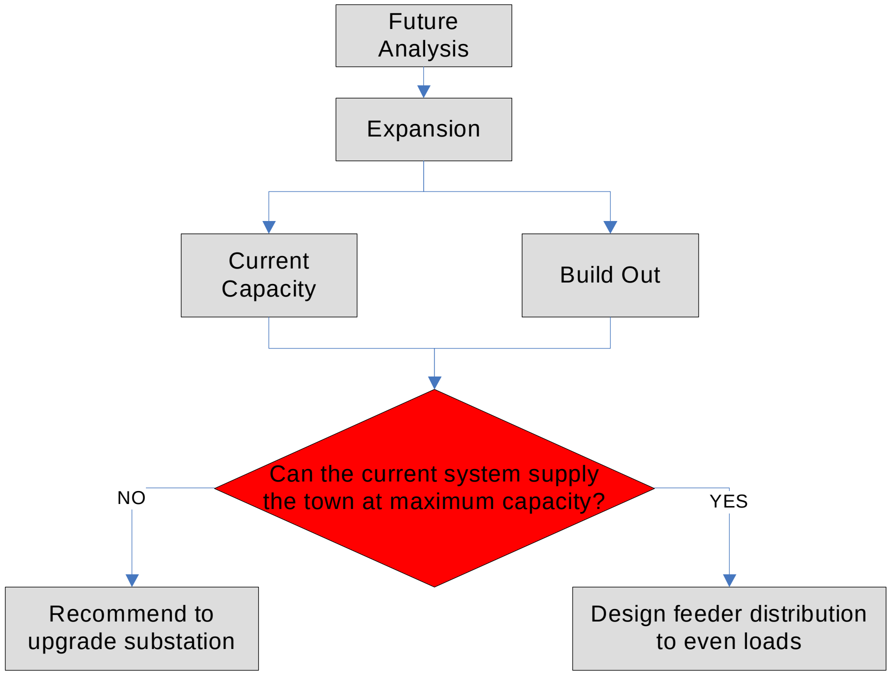


Figure 23 System Capacity Analysis Flowchart

The maximum build out population based on the zoning reported by the CMRPC is expected to be 9,967. Based on the ratio population of the current system to customers, we came up with a multiplicative factor of 2.37. This number assumes that the commercial, residential and industrial customers will increase in a linear fashion. Using this ratio, the number of commercial, residential and industrial customers of a completely built out town of Boylston is 4,984. The next step is to see if the Light Department can withstand the maximum usage of the future customer estimation.

4 Results & Analysis

This chapter summarizes the results of our project including; the inventorying of the current components, recommended replacement of components and projected expansion of the system. These results with both help the Town of Boylston assess their current system and begin upgrading, as well as hopefully allow for future project expansion and continued modernization.

4.1 Inventory of Components

This section describes the results of the components inventoried within the constraints of this project including results by type and year installed. Major components inventoried and analyzed include transformers, poles, and overhead primary lines.

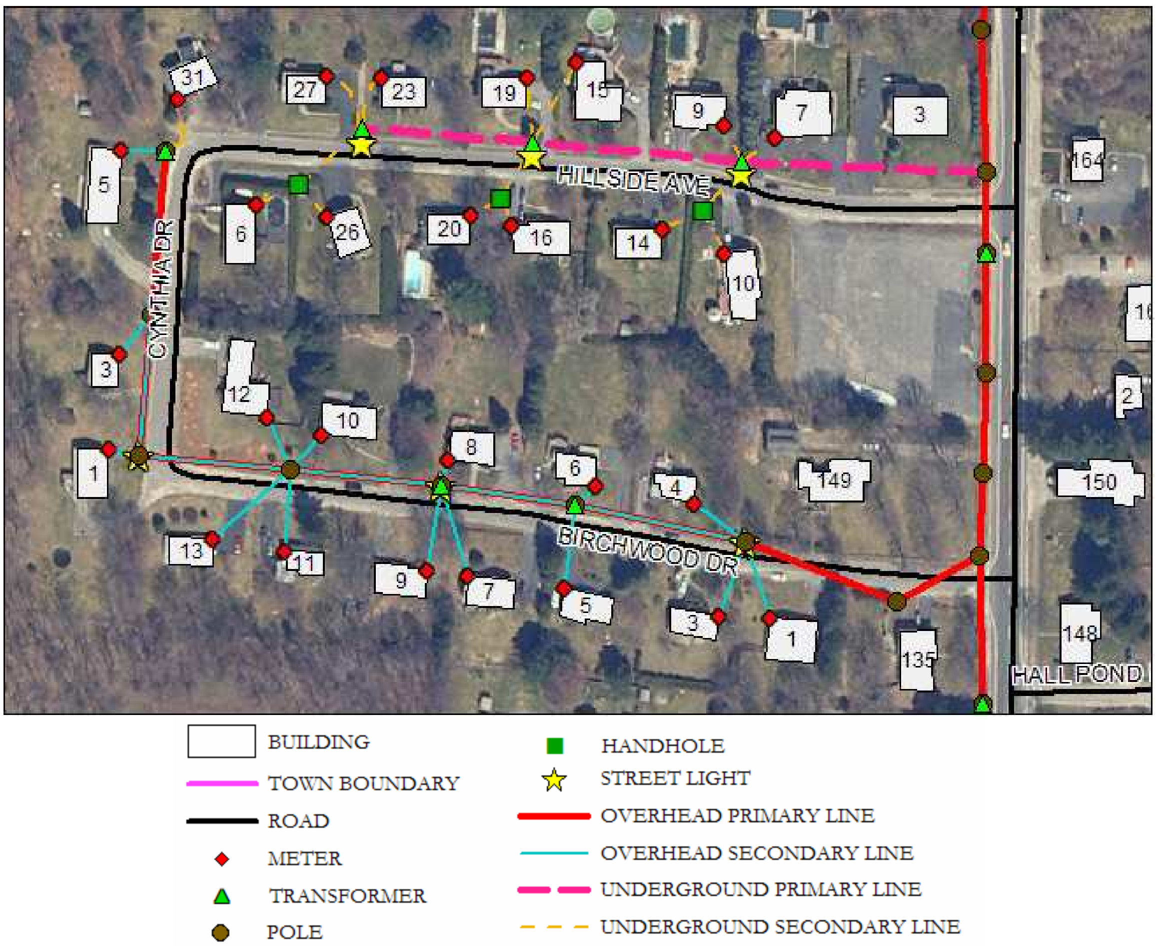


Figure 24: Example of Geospatial Inventorying for Boylston's Electrical System

4.1.1 Inventory of Poles in Boylston

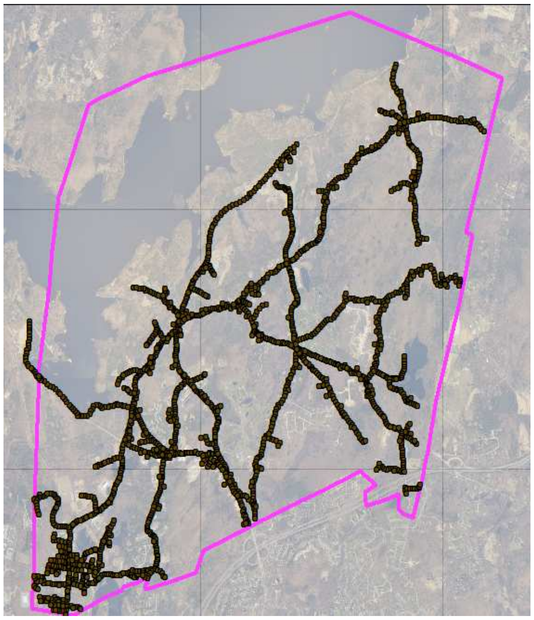


Figure 25 Pole Inventory Results

In total 2,130 poles were inventoried into the databases and placed within the MapInfo layers. The result of all the poles inventoried can be found in Figure 25. Pretty much every main street in Boylston is lined with poles excluding a good number of smaller streets with underground electric infrastructure. The poles currently present within Boylston have been set between the years 1920 and 2007.

Error!

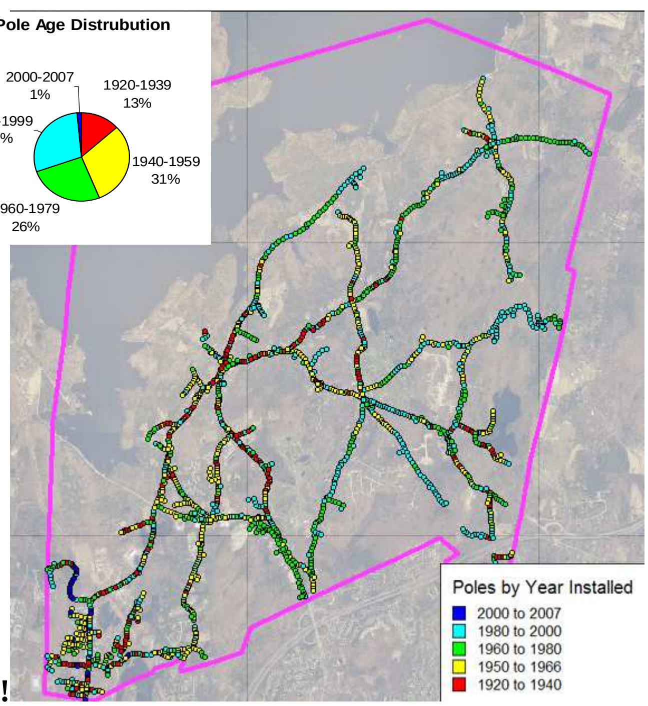


Figure 26: Poles Mapped by Year Installed

The poles within Boylston are pretty randomly scattered by age as can be found in Figure 26. The distribution is relatively even, except for a very small amount of poles that have been installed in the last seven years.

4.1.2 Inventory of Transformers in Boylston

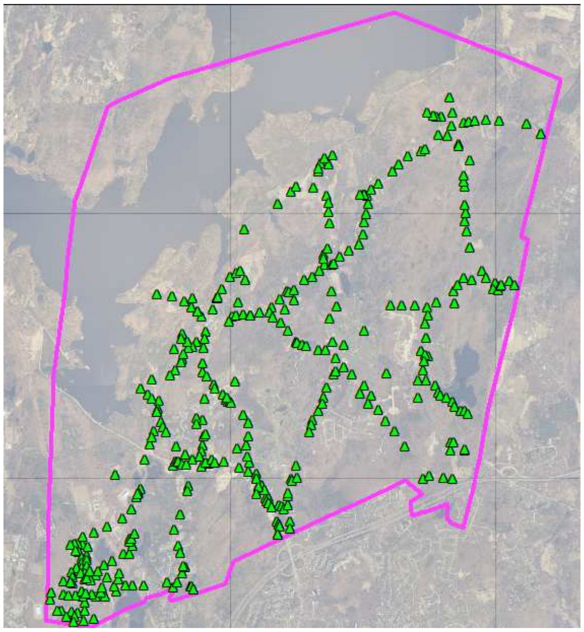


Figure 27 Transformer Inventory Result

In total 400 transformers were mapped and inventoried within the city limits of Boylston. The transformers inventoried include mainly pole mount units with are fed directly from the overhead primary line system but some pad-mounted transformers have been included. As with the pole map already shown above, the transformers also follow the streets of Boylston in many cases.

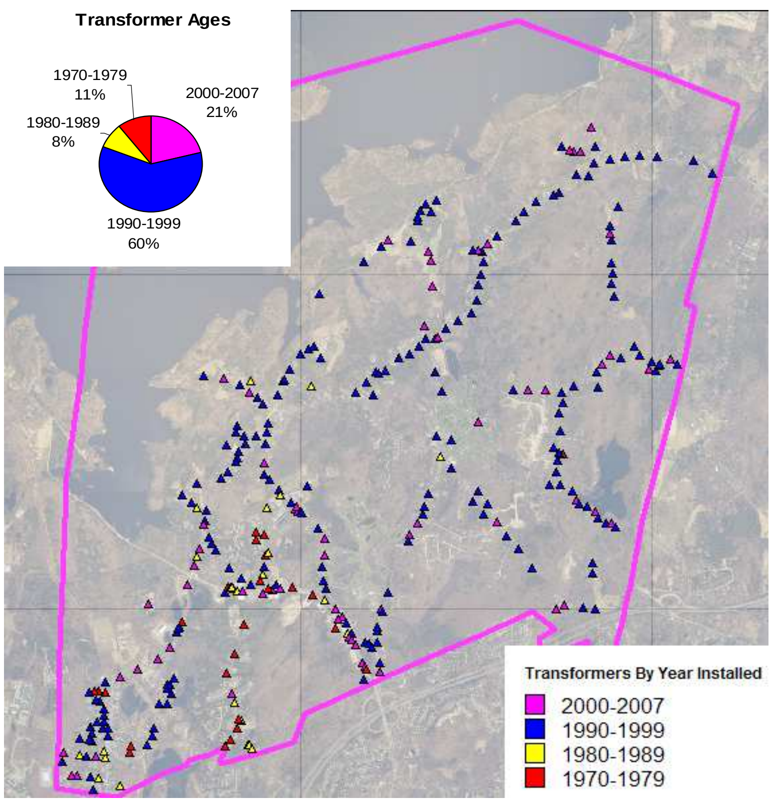


Figure 28 Transformers Mapped by Year Installed

Transformers, unlike poles, have a much shorter life span and Boylston has installed more then three quarters of their transformers in the last twenty years.

4.1.3 Inventory of Overhead Primary Lines in Boylston

The high voltage overhead primary lines in the town are broken up into two circuits that service the northern and southern parts of the town separately. The figure below shows this separation with the northern and southern feeders color-coded red and blue, respectively. Both feeders exit the sub-station in West Boylston side by side and go to feed all the transformers within the town. In total 41 miles of overhead primary line were mapped including 23.5 miles belonging to the North Feeder and 17.5 miles for the South Feeder.

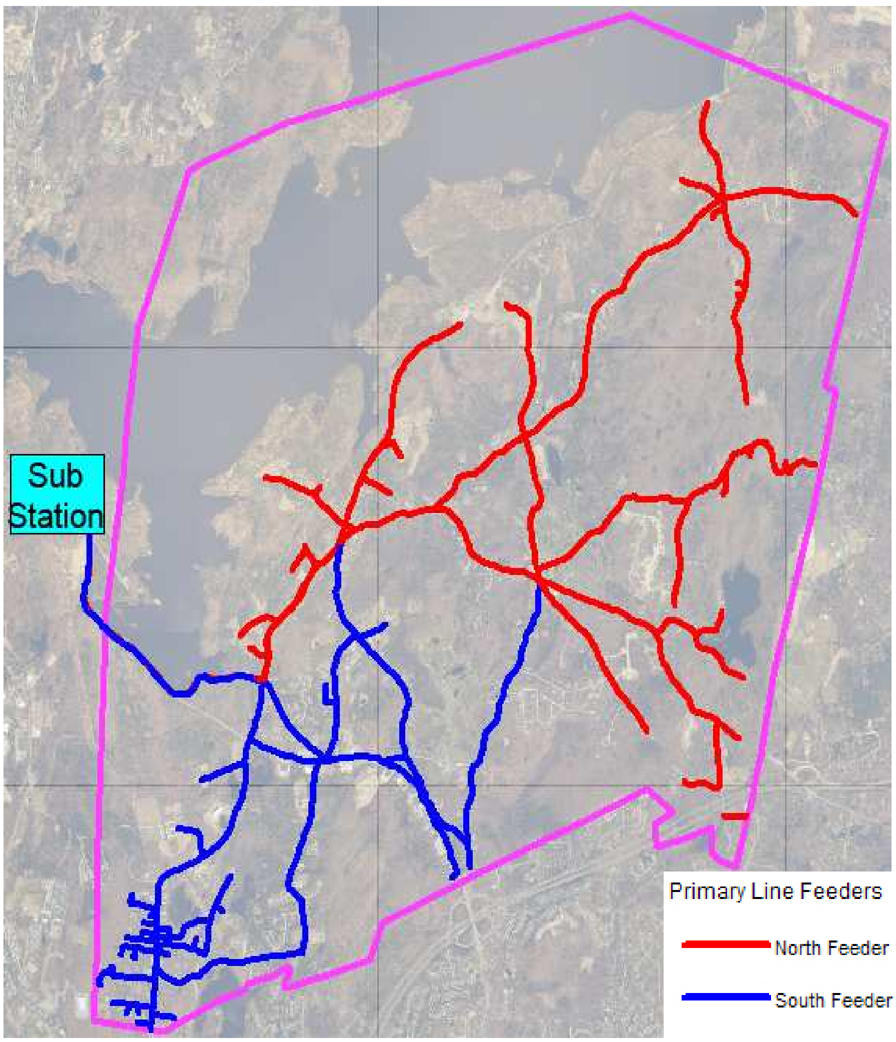


Figure 29 Overhead Primary Inventory Result

4.2 Estimated Costs for Infrastructure Upgrades

With the use of all this newly computerized data it is now much easier to quickly identify older and inadequate equipment within the system. After the system inventory it is recommended that Boylston Light Department consider upgrading old poles and transformers, as well as certain segments of smaller diameter overhead primary line present within the system.

4.2.1 Poles to Upgrade

Aging poles within an electric system can cause unsafe conditions due to the high voltage lines they carry. By doing preventative maintenance to the system now, Boylston Municipal Light may be able to avoid costly downtime of their electric system and increase customer satisfaction.

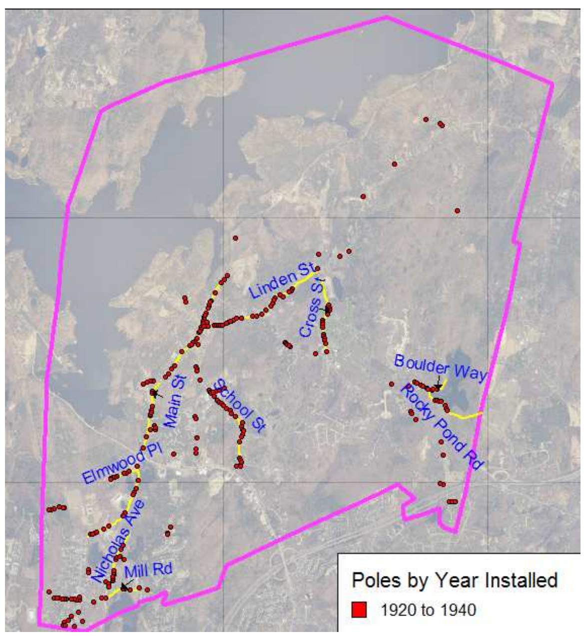


Figure 30: The Oldest Poles Present in Boylston

A key point to note is that many of Boylston's oldest poles are found on core streets such as Main Street, School Street, and Linden Street. Failure of aging poles on these streets as seen in Figure 30 could cause a large number of customers left without power due to the main feeders that lie on these key streets. If all poles shown in Figure 30, which were installed pre-1940 were to be replaced with the same height pole at today's market cost the total replacement would come to $46,278.

4.2.2 Transformers to Upgrade

Old transformers lead to both lower efficiency and less reliability in an electrical system. Boylston's electrical system has 37 transformers spread throughout the town that were put into service pre-1980, represented in Figure 31 below.

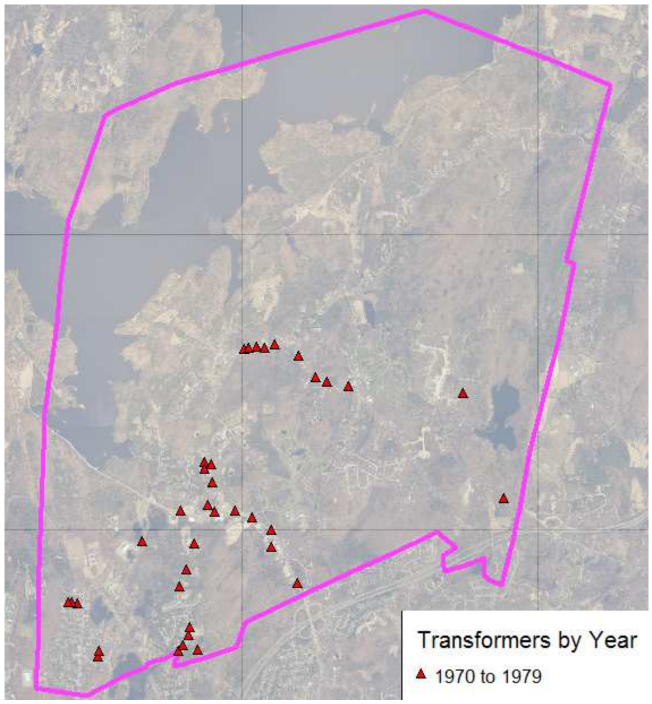


Figure 31 The Oldest Transformers Present in Boylston

With the rising costs of energy replacement of these transformers would led to less loss of profit on Boylston's behalf. Older transformers when fully loaded may only have an efficiency of 95% were as a new transformer bought today would have an efficiency of closer to 99%; this reduction of loses will led to greater profits and the transformers paying for themselves in the long run. It is recommended to replace 35 of the 37 old transformers with new models. The replacement of two large size pad mount transformers is not advised due to cost constraints. If these 35 transformers were to be replaced with the same size unit at today's market price the cost would total $44,400.

4.2.3 Primary Lines to Upgrade

The main branches of the high voltage feeder system present in Boylston's electric infrastructure consist of 15 kilovolt aluminum tree wire of varies sizes. In Figure 32 above you can see the three sizes present with 3/0 being the smallest and 336 MCM being the largest wire size.

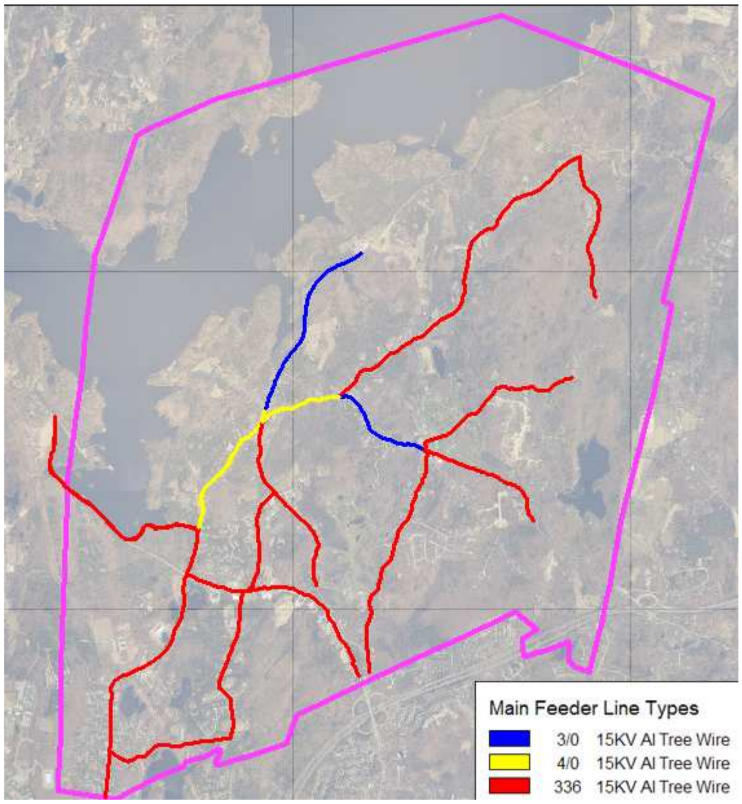


Figure 32: Main Feeders of Boylston's Electrical System Mapped by Size

In a perfect situation the wire size would remain consistent as the branches get farther away from the sub-station. For these reasons it is our recommendation to replace the 3/0 and 4/0 segments of line in the above map with larger 336 MCM size aluminum tree wire, with a replacement cost of $1.86 per linear foot. Since this spaced tree wire requires three lines running parallel to each the necessary length of for this upgrade is three times the total segment length to be replacement making this a costly improvement. In total, the blue and yellow portions on the above map represent just under five miles of electrical lines in which it would cost $143,173 to replace.

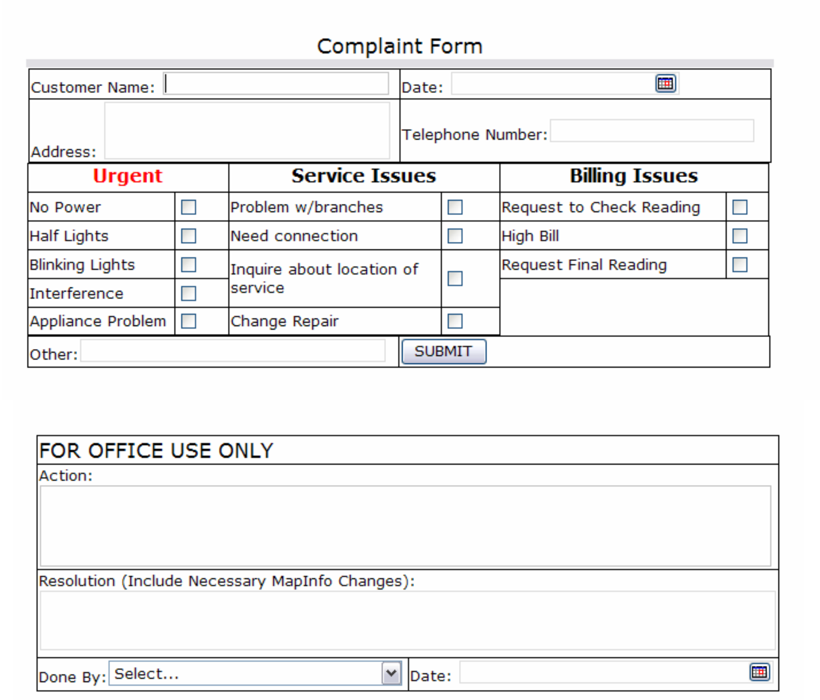
4.3 System for Information Upkeep

After carefully studying the current processes of the Light Department, the design of new forms was finalized. Also, a step was added to the process of new subdivision development, with the intention of making it easier for the Light Department to retain information during this process. The last step was to put all of the pieces together and create an example of how the Light Department will operate in the future, from the employee and customer perspectives. The results from these analyses can be found the following sections.

4.3.1 Electronic Complaint Form

The current complaint form can be confusing in that some of the fields are problems and some are solutions to those problems. Also, this form lacks any way to tell urgent problems from simple maintenance tasks. Lastly, the form has no place to record what action was taken to resolve the problem. This is useful to record because if there is a recurring problem it can be seen what actions were previously taken.

When designing the new form it was kept in mind that in the future Light Department customers will be able to fill it out online. The type of issue and its urgency were used to create three categories of issues. Also, the form was split up into two parts; one for customer use and one for office use only. The first part contains areas for the customer to fill out his or her information and the problem that they are experiencing. Once this part is completed, there is a "SUBMIT" button that is clicked, sending the form to the Light Department office. After this form is received it is placed into a database of issues, ranked by urgency. The secretaries will then assign the problems to lineman who will execute the necessary steps to solve the problem. The second part of the form will be filled out with the resolution of the problem once the problem is closed. This will include any database changes that need to be made. The form will be filed electronically to end the process. The new complaint form that was created can be seen in Figure 33.



Complaint Form

Customer Name: | Date:

Address: | Telephone Number:

Urgent		Service Issues		Billing Issues	
No Power	☐	Problem w/branches	☐	Request to Check Reading	☐
Half Lights	☐	Need connection	☐	High Bill	☐
Blinking Lights	☐	Inquire about location of service	☐	Request Final Reading	☐
Interference	☐				
Appliance Problem	☐	Change Repair	☐		

Other: SUBMIT

FOR OFFICE USE ONLY

Action:

Resolution (Include Necessary MapInfo Changes):

Done By: Select... Date:

Figure 33: Updated Complaint Form

4.3.2 Electronic Wiring Inspector Form

The other form that was updated is known to the Light Department at the "Wiring Inspector Form." This form is filled out by the town wiring inspector when he performs an inspection of a residence, and is used primary for notifying the Light Department of the status quo of the building. Some billing information can be pulled off it as well. It required some minor field changes and reorganization, but the main objective for updating it was to make it electronic. This will allow the Light Department to receive the form from the wiring inspector's office and import the data electronically. The name of the form was also changed to "New Hookup Form" because it better reflects the purpose of the form. A copy of this improved form can be seen in Figure 34.

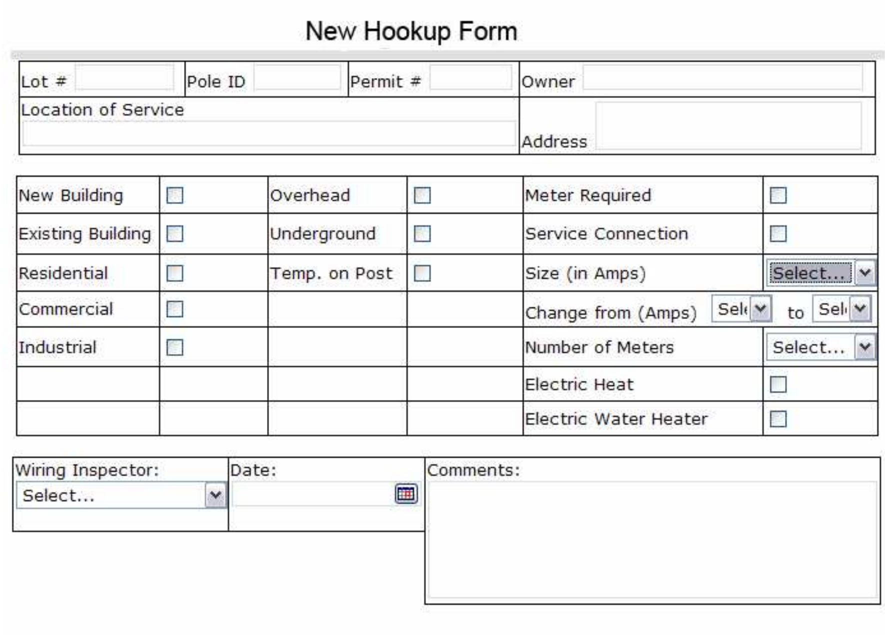


Figure 34: Updated New Hook-Up Form

4.3.3 New Subdivision Development Process Update

A flowchart showing the process for creating a new subdivision in the town of Boylston can be found in chapter 2. The main part of this process that needed to be changed was at the end of stage one. During this part of the process the work is done and all components are in their final places. It is at this point that the information about the subdivision can be imported into the database. But seeing as how the location of components could have changed since the beginning of this process, it is necessary to request the contractor to submit an electronic "as-built." This is a copy of what the final subdivision looks like, usually drafted by an engineering firm. This request would have to be found in the planning regulations of the town. An example of the wording of such a request can be found on page 26 of the *Subdivision Regulations* of Spencer, Massachusetts:

> As-Built Survey. Upon Completion of the roads and infrastructure and prior to the final release of any covenant and/or surety, the developer shall submit four copies of an as-built survey to the Planning Board. The as-built survey shall show the boundary lines of the rights-of-way and lots within subdivision, the location of streets, the names of streets, sidewalks, drainage structures, underground utilities (including sewer, water, storm-water, electric, telephone, cable television, and gas, fire cisterns, signage, street lights, and street trees).

The document goes on to state that this as-built will need to be stamped by a surveyor or engineer and must meet Level III of the current version of the MassGIS Standard for Digital Plan Submission to Municipalities. These are standards defined by MassGIS that outline what exactly needs to be submitted in order to meet each submission level. Of course not everything in the above statement applies to the Light Department, but with the inclusion of the electric components in the as-built they would be able to use it to enter in accurate data for the subdivision. This change in regulations will have to come from the town planning board because it would be unreasonable to have only the Light Department requiring the as-built. Also, a monetary incentive can be used to persuade developers to comply with certain levels of submission. The higher level they comply to, the less they will have to pay to receive certain permits.

This above statement is just an example of how the document can read, but will need to be changed to suite the needs specific to the town of Boylston. The final statement will have to include the location of all, transformers, handholes, streetlights, and underground lines. The type and size of all components will already be recorded in the Light Department's database, and therefore will not need to be added here. Once this system is in place it will be very simple for the Light Department to import information regarding new subdivisions into their database.

4.4 Additional Analytical Capabilities of the System

The numbers provided in the Methodology section 3.4 are useful in finding the maximum usage of the build out population. This section will go one step further to determine what the best plan of action is.

4.4.1 System Capacity

The peak of the system at full expansion is 17,340 kW. The substation is able to withstand 24 MW, therefore the system can handle the town of Boylston at its full build out population. The only downfall of the system is the layout of the primary lines or feeders from the substation. Figure 35 shows the current layout of the feeders.

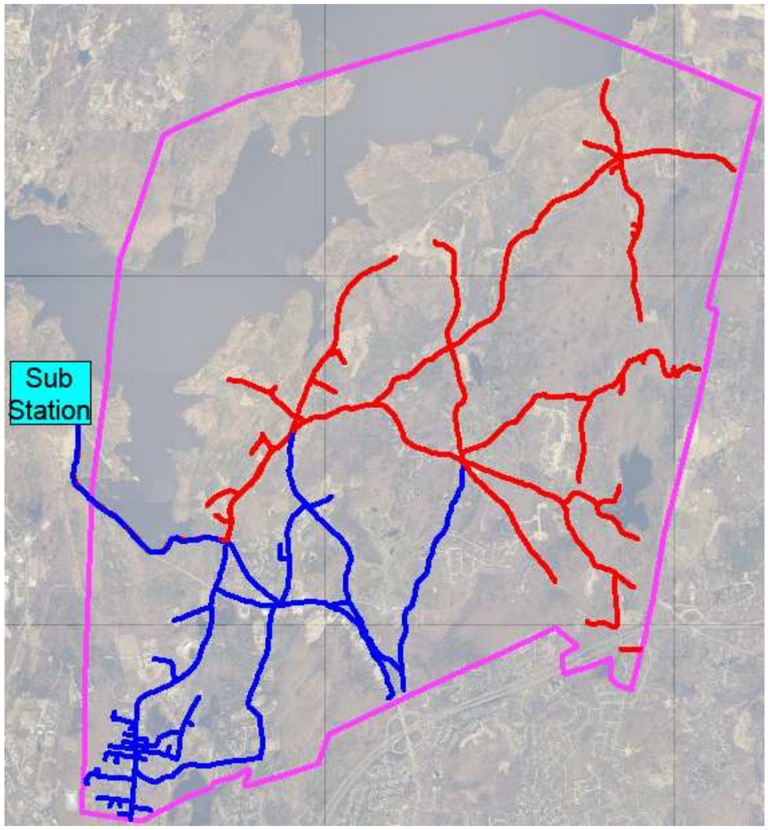


Figure 35: Current Feeder Design

The Boylston substation has 3 available feeders but is currently only using 2 of them. The blue feeder in Figure 35 is supplying the most densely populated area of Boylston; therefore the population of this section will not increase greatly. North of the blue feeder is the Wachusett Reservoir that is not land that can be built upon. The northeast section of Boylston is where the most subdivisions will be built. As of now the loads on the feeders are somewhat balanced, however with the majority of the expansion happening in the red feeder's vicinity, the loads will become unbalanced. With that in mind, we propose that Boylston utilizes its 3rd feeder to balance the loads into 3 sections as shown in Figure 36. Using the existing primary lines this process would not be difficult or costly.

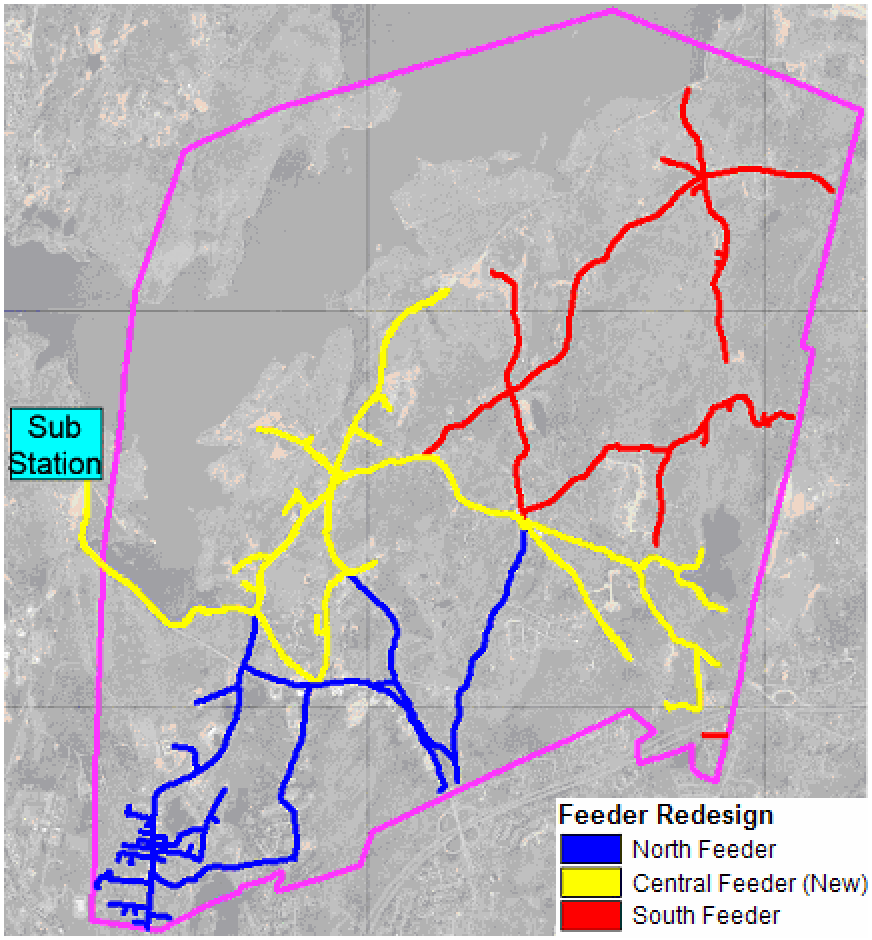


Figure 36: Proposed Feeder Design

5 Conclusions & Recommendations

Due to time constraints and limited resources, there are some areas of this project that can still be explored further. Also, now that there is a functioning database other analyses will be possible in future projects. It is important that the data acquired as part of this project not be wasted, but put to good use helping the Town of Boylston. The following sections show how much this project has completed, as well as what tasks can be taken on in the future.

5.1 Short Term Recommendations

Inventorying components was a difficult task that required pulling information together from many different sources. Paper records from the Light Department were combined with a map from Charter Communications to result in the final maps. In order to ensure accuracy throughout mapping, great care was taken to confirm the exact location of components. This being said, the inventorying part of this project was not completed, but it was left at a stage that makes it easy to pick up. The following chart shows the progress that was made on the major components.

Component	Amount Inventoried	Estimated Total Amount	Amount Remaining
Poles	2,130	2,200	70
Transformers	400	598	198
Overhead Primary Lines	41 miles	45 miles	4 miles
Street Lights	49	150	101

Figure 37: Inventory Completion

The following is a list of components that were mapped primary in the Morningdale test area. Databases were created for them, so it will be easy for the Light Department or a future project to fill them in with the rest of the components.

Components
Meters
Handholes
Overhead Secondary Lines
Underground Primary Lines
Underground Secondary Lines

Figure 38: Remaining Components to be Inventoried

Completing this inventory would provide a good basis for a future project. Most of the new inventorying will have to be done using the paper blueprints for subdivisions. This is where most of the underground components are found. Also, more houses need to be added in the northern part of town, because they were not drawn in by the members of the Boylston Water team since not all houses in this area have water.

5.2 Intermediate Recommendations

Once the inventory of the entire system is complete there are certain goals that the Light Department will be able to achieve. With the databases and maps completed it will be possible for the town execute these tasks that were previously very difficult. Two such tasks are fuse coordination and load balancing. Both of these would greatly improve the efficiency and reliability of the system. Also, older components have been identified, and plans for replacement have been recommended.

5.2.1 Fuse Coordination

A major problem that is faced by power companies is the occurrence of widespread power outages. These can result in an inconvenience or even a dangerous situation for customers. To avoid this problem power companies execute what is known as fuse coordination. The goal of this coordination is to isolate an outage so that a minimum number of customers are affected. Currently, the Light Department is capable of fuse coordination with their limited knowledge of the system, but with the entire system mapped out a better analysis will be possible. It is recommended that once the databases are complete, a fuse coordination be executed by either the Light Department or a future project.

5.2.2 Balancing Loads

The balancing of electrical loads not only on the entire system, but also on individual components is vital in making certain that the system is working to its maximum potential. Previously discussed was the redesigning of feeders to balance loads, but it is also necessary to balance the loads on each transformer in the system. Currently, it would be difficult for Boylston to perform this analysis, but with the information mapped out through this project it will be possible. The databases provide the tools that will be used to calculate the actual load on every transformer in the town. Once this is completed, it will lead to the repositioning and/or replacement of transformers. This will result in transformers of the correct size in the correct location, based on the amount of power they need to provide.

5.2.3 Plan for Updating Poles and Transformers

The cost for updating old components was discussed in Section 4.2 and will be expanded upon here. The important part of upgrading components is to set up a timetable of replacement that will make it affordable for the Light Department. The following map shows the poles and transformers that are recommended for replacement. Namely, poles installed between 1920 and 1940, and transformers installed before 1980.

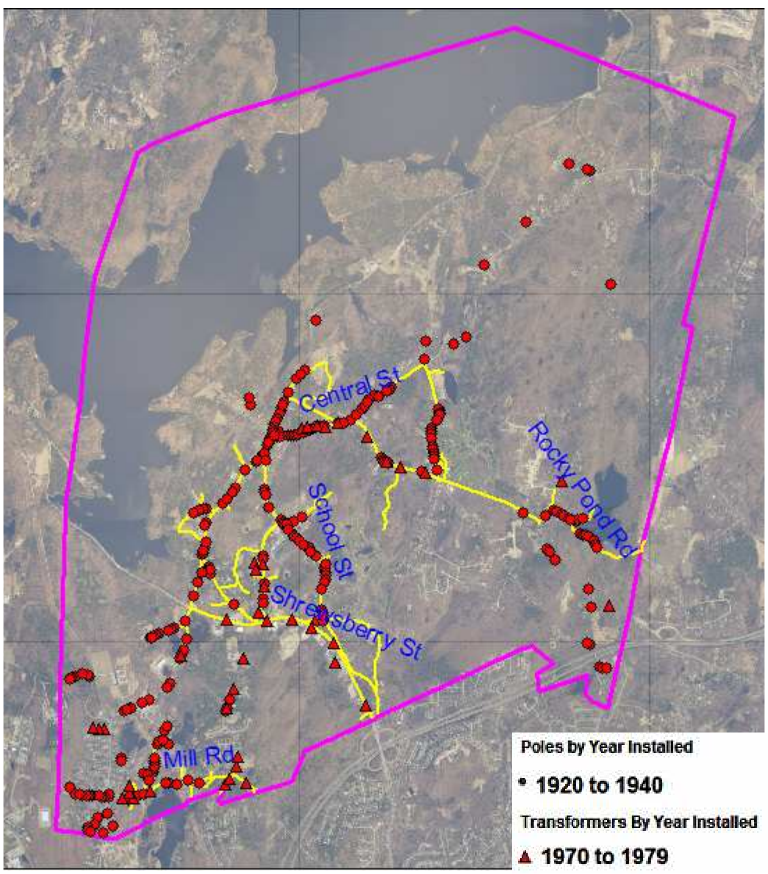


Figure 39: Poles and Transformers Recommended for Replacement

Due to the fact that these components are likely nearing the end of their usable lifespan, it is recommended to create a replacement plan that will span the next few years until these components are successfully replaced. In total, there are 223 poles and 35 transformers in these age categories. The total cost of replacing all of these components at once is around $90,000. It is unrealistic to think that the Light Department would be able to come up with this amount of money all at once, but if spread out over time, it would be feasible. The Light Department could implement a five-year plan that would include replacing 40 poles and 7 transformers a year, starting with the oldest of each.

The main affected roads are Rocky Pond Road, School Street, Shrewsbury Street, and Mill Road. It is interesting to note that these are major streets in the town, which carry primary lines. Failure of the components in these areas would result in widespread outages. This creates unsafe conditions for customers and hurts the business of the Light Department.

5.2.4 Plan for Updating Overhead Primary Lines

Another component that is recommended for replacement is overhead primary lines. In many places the lines are not a consistent size, which results in efficiency (see Figure 32). The lines jump from large to small and back again, which is not ideal. The recommendation here would be to homogenize the lines in order to allow the electricity to flow better. This will result in a longer timetable for replacement because the replacement of the lines is far more expensive than poles and transformers. The cost for replacing all five miles of the smaller diameter aluminum tree wire is around $145,000. A ten-year plan is recommended here, which would result in replacing a half-mile of line a year at a cost of around $14,700. The group feels that this is a reasonable recommendation that will be considered by the members of the Light Board.

5.3 Long Term Recommendations

There are also some recommendations to be made for the system in the long-term. Down the road it may be necessary for the Light Department to redesign the feeder layout of the system as discussed in Section 4.4.1. Based on the current developmental trends they may reach a population that will result in the need to place a third feeder throughout the town.

Another long-term recommendation is the use of an online system to manage the Light Department. This system will include the forms and processes that were discussed in this report. In the future, customers will be able to log onto the Light Department website and report a complaint electronically using the new form. Once this is submitted, it will go into a database of complaints ranked by urgency. From there, a Light Department office worker will assign the problem to a worker, who will take care of fixing the problem. Once the work is completed, the second part of the complaint form will be filled out and stored electronically, and the complaint will be set to "Closed" in the database.

This is just one example of the new capabilities of the future system. Other examples include the potential for component analysis to be conducted on the system with a few mouse clicks, and of course, the ability to add components as necessary. All of these functions can be tailored to exactly what the Light Department needs and wants to be able to accomplish. An example of the user interface that will make all of this possible can be seen in Figure 39.

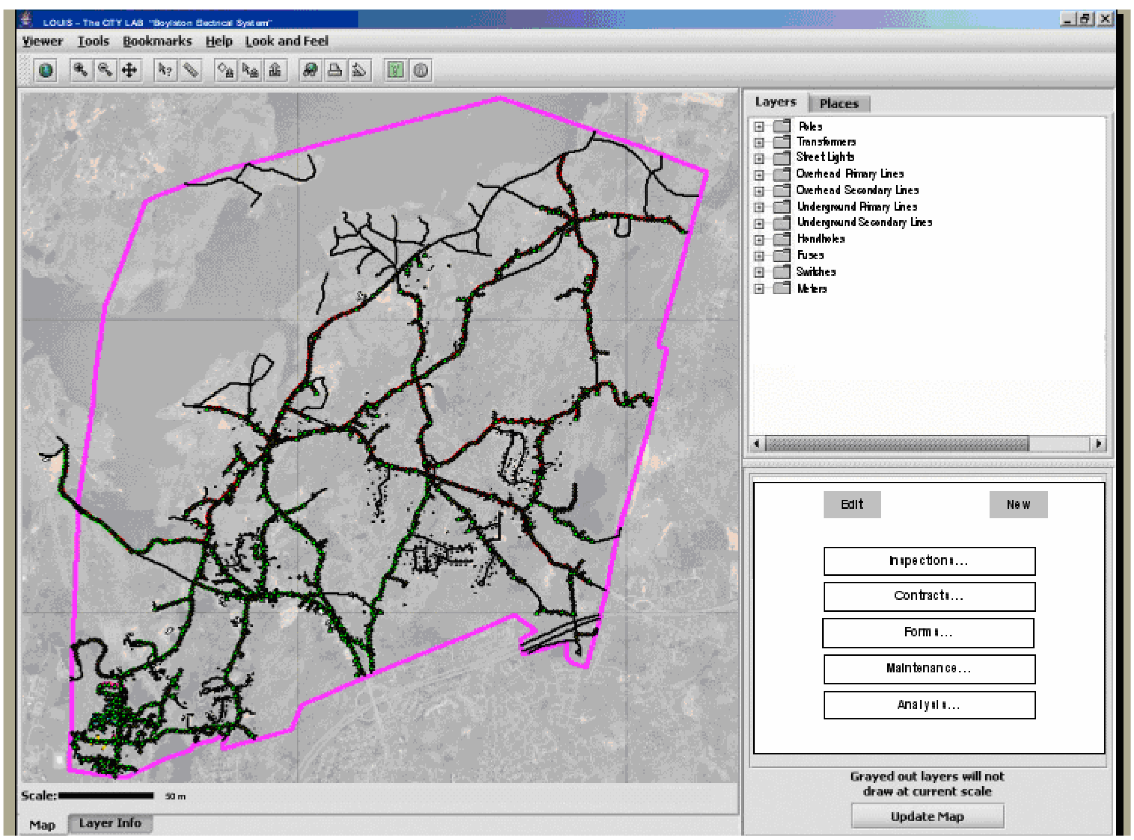


Figure 40: Mockup of the Future System

6 References

Annual reports of the town officers of Boylston, Massachusetts for the years ending in December 31, 2005. 2006.

Annual reports of the town officers of Boylston, Massachusetts for the years ending in December 31, 2004. 2005.

Annual reports of the town officers of Boylston, Massachusetts for the years ending in march 1, 1912. 1912.

Adel, Boumallala. Technical specification of the single phase distribution transformers. 2006]. Available from http://www.ttransfo.com/pdf/Mono_eng.pdf.

Alabama Power. Today's power system. 2007]. Available from http://www.southerncompany.com/alpower/storm/tps.asp?mnuOpco=apc&mnuType=sub&mnuItem=ni.

American Public Power Association. Public power: Shining a light on public service. 20062006]. Available from http://appanet.files.cms-plus.com/PDFs/PPFactSheet.pdf.

"It's your future....." A report of the APPA task force on public power in the 21st century. in ResultsDirect.com [database online]. 2002 [cited September 21 2006]. Available from http://www.appanet.org.

Brain, Marshall. How power grids work. in How Stuff Works Inc. [database online]. 2006 [cited September 22 2006]. Available from http://www.howstuffworks.com/power.htm.

Copper Development Association. Transformer life-cycle cost (total owning cost). 2006]. Available from http://www.copper.org/applications/electrical/energy/trans_life_cycle.html.

Dupuis, William O. 1972a. History of the town of Boylston 1786-1886.

1972b. History of the town of Boylston 1643-1741.

Electri-Glass, Inc. Handhole splice boxes. 2006]. Available from http://www.electri-glass.com/handhole.htm.

ERMCO Components, Inc. Low voltage breaker transformers. 2006]. Available from http://h-jinternational.com/pics/csp_concept/LV_breaker_transformers_brochure.pdf.

Integrated Publishing. The electrical engineering training series: Transformer ratings. 2006]. Available from http://tpub.com/neets/book2/5i.htm.

Kurtz, Edwin B., and Thomas M. Shoemaker. 1992. *The lineman's and cableman's handbook*. 8th ed.McGraw-Hill Inc.

National Grid. What's yours, what's ours - whose responsible for your electric and gas services. 20052006]. Available from http://www.nationalgridus.com/non_html/shared_yours-ours.pdf.

Stephens, Phil. Handholes and underground electrical enclosures. 20032006]. Available from http://www.nfpa.org/itemDetail.asp?categoryID=1025&itemID=25202&URL=Publications/necdigest%20Magazine/necdigest&cookie%5Ftest=1.

Vennard, Edwin. 1979. *Management of the electric energy business*. United States of America: McGraw-Hall Inc.

Appendices

Appendix A: History of Boylston

The history of the town of Boylston dates back as almost as far as the history of America itself. Thomas King purchased the land that Boylston currently stands on from Sholan Sachem of the Nashua Indians in 1643. This parcel of land was 10 miles wide by 8 miles from north to south, making it much bigger than present day Boylston. It included other towns that currently border Boylston. Shortly after buying the land, King sold it to a group of three men: Smith, Waters, and Hall. At this point the land was to be prepared for settlement, but this process was taking a long time and only nine families resided in the entire area. On May 8, 1653, this handful of residents received their wish for township, and the area was incorporated as the town of Lancaster.

From their time of incorporation until 1676 the residents of Boylston lived peaceful lives. But in 1676 that changed with a bloody Indian raid that caused much destruction in the town. Ironically, this raid was lead by the grandson of Sholan, the Indian that originally sold the land to King. After this raid there were no inhabitants in Lancaster for more than three years. The town was rebuilt in 1679, and from then until 1692 there was peace in the region. The year 1692 saw another bloody raid, in which some of the residents lost their lives. During the following years there were more Indian attacks and in 1704 the French and Indian War came through the region. The last act of Indian violence was in 1710. During these early years Lancaster can be described as a frontier type settlement with scattered homes throughout the region. Many families came in and out of the town due to the Indian violence. The first permanent settler was John Prescott.

The town of Lancaster purchased more land in 1713 and grew for the next 30 years. During this time settlers started to fill the region, but the town maintained a central meeting house. Finally some of the settlers were tired of making a long trip to get to the meeting house and they decided that they wanted to form their own towns. One of the new towns, formed in 1742, was known as the North Precinct of Shrewsbury. It was at the southern part of Lancaster and bordered Shrewsbury to the south. This North Precinct would eventually be called Boylston in 1786, and was made up of what are currently Boylston and West Boylston (which seceded in 1808). The town was named after the prominent Boylston family of Boston. Ward Nicholas Boylston of Princeton gave 40 pounds in 1799 and Thomas Boylston of Boston and London willed 1500 pounds in 1816 to be used to finance the building of a school.

The coming period would not be a so-called “boom” period for the town, but rather the townspeople held their own and did, in fact, make some progress economically. Their population, on the other hand, declined steadily from 1800-1830. This was partly due to the breaking away of West Boylston, but can manly be attributed to the fact that people during this period did much traveling looking for work, rarely settling down in one place. The most popular occupation continued to be agriculture and political, as well as religious, life was centered at the town meeting house. Despite the popularity of agriculture, the Nashua River, a good source of water supply, attracted some mills to the area.

The town meeting house remained the central of political and religious life until 1830 when the town hall was constructed, followed by the third meeting house in 1835. Residents were quoted as saying that the second meeting house was becoming run down and “cheerless.” This was only the start of a period marked with growth and prosperity. Between the years of 1827 and 1846 farmers and artisans produced record numbers of crops and manufactured goods.

Around the middle of the 1800’s the community started to see some changes. A spur line of the Agricultural Railroad was built through the town in 1856. Four years later Main Street was laid out and constructed. Soon after, immigration hit the town, permanently altering its social makeup. During this period more schools were erected and the first high school class was held in 1852. Also, the political structure of the town was greatly changed, as the decision was made in 1847 to elect only three selectman instead of five. This put more power in the hand of each selectman. Along with the afore mentioned changes, this period was also marked with much controversy over land, buildings, and religion. However, by the middle of the 1860’s Boylston was returning to a peaceful environment, the town was prosperous, and the residents continued to work hard. The town was able to look back on its first 100 years with nostalgia and pride.

For the rest of the 1800's the mills that had come to the town at the beginning of the century began to thrive. A main railway was put in during 1870 causing the village of Sawyer's Mills to become a prosperous industrial community. Half of Boylston's tax base and population depended on it by 1895. But the construction of the Wachusett Reservoir brought a halt to the mills and the thriving industrial community. Many families were forced to leave to find work and homes elsewhere, but the town's population grew from immigrants coming to work on the reservoir. This can be seen in the population growth chart, Figure 38, and in the chart depicting the amount of immigrants in Boylston, Figure 39.

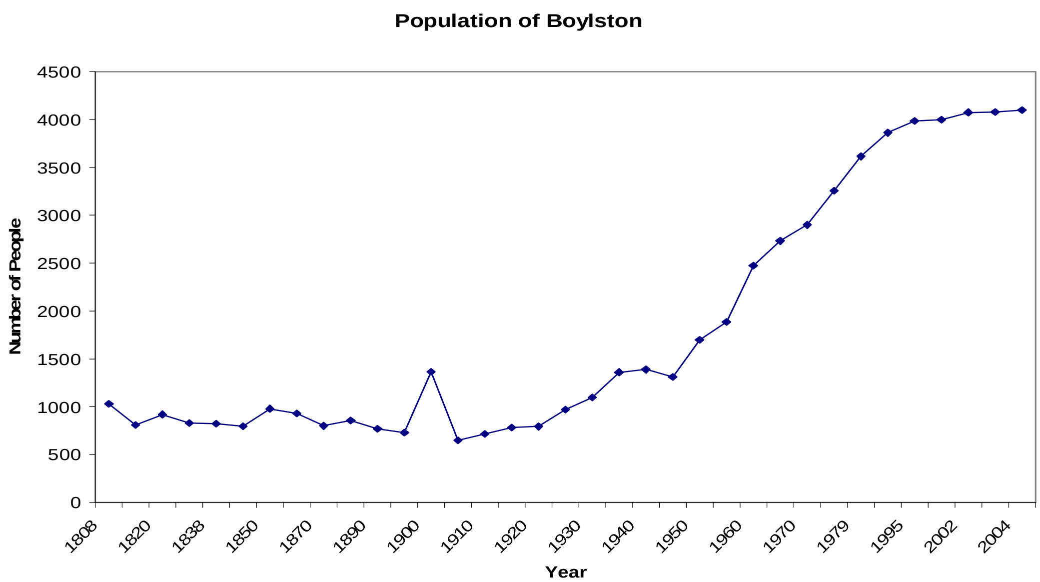


Figure 41: Population Growth of Boylston

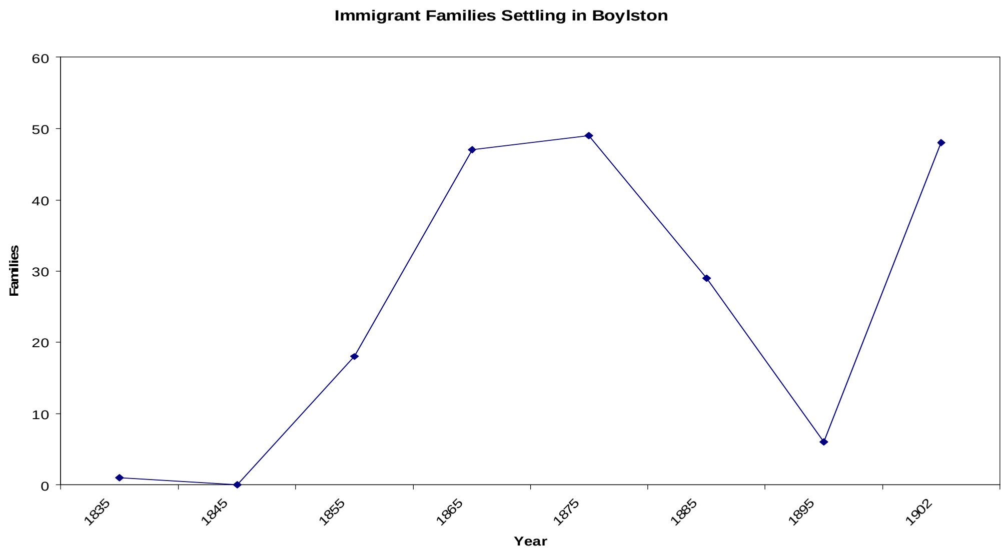


Figure 42: Number of Immigrant Settling in Boylston

Overall the town lost 302 residents and 2761 acres of land. Much of this land was prime farmland. Having an area of almost seven square miles, the reservoir is the second largest body of water in the state of Massachusetts. This hurt the town, but growth would resume after World War II. Once the servicemen came back to the area, building grew in the Morningdale area to meet the new housing demands. Also, the completion of highways I-290 and 495 spurred the surge of building and allow the residents of Boylston to access major cities. Although there was economic growth in the community during this time, as seen in Figure 43, industry and agriculture were mostly gone in the town.

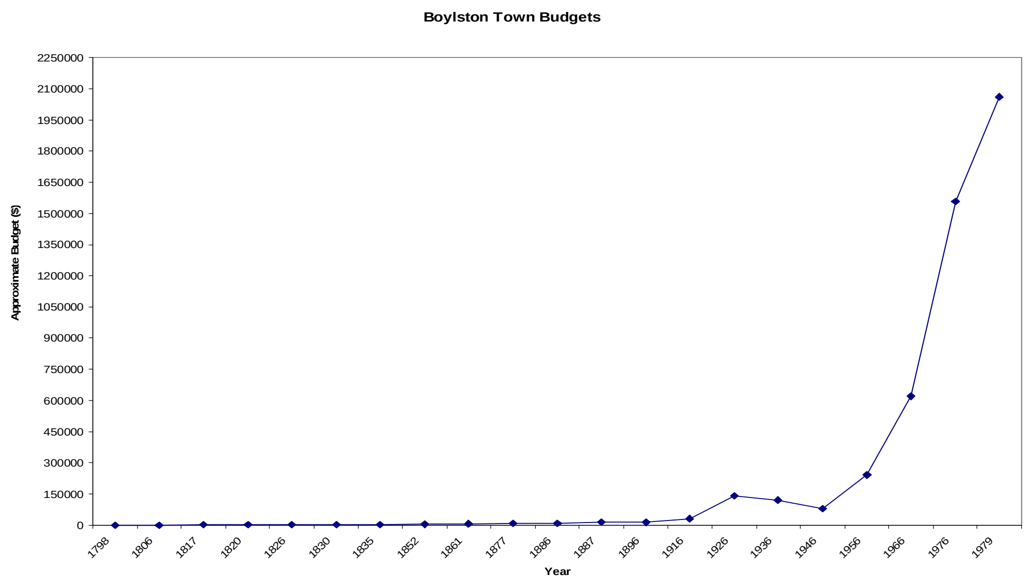


Figure 43: Trend of Boylston Town Budgets

Today, the town of Boylston has around 4,100 residents. It is still governed by three elected selectman as its executive body and by town meetings as its legislative body. Boylston lies in Worcester County on 10.5 square miles of land. The town maintains approximately 45 miles of roadway, has a semi-public light department, and two water districts. The town is part of a regional school system that includes the town of Berlin. The kindergarten through sixth grades are housed in a non-regional building, while grades seven through twelve are housed at Tahanto Regional High School, on Main Street in Boylston.(Anonymous2005; Anonymous2006; Dupuis 1972a; Dupuis 1972b)

Appendix B: Boylston Municipal Light Statistics

Year	Gross Revenue	Profit	KW of Demand	KWH Bought	Customers	Avg. Cost (KW)	Avg. Cost Adjusted
2004	2850902	68749	6169	30416531	2140	0.0991	0.1
2003	2828718	64984	5836	29864586	2098	0.102	0.11
2002	2823644	64417	5967	28973759	1763	0.105	0.11
2001	2819530	19678	5860	27992115	1763	0.108	0.12
2000	2658859	67277	5600	28131673	2113	0.105	0.12
1997	2405593	75745	4760	24671276	2026	0.082	0.1
1996	2274755	108160	4880	24166787	1998	0.0801	0.1
1995	2158481	21122	4960	23392306	1972	0.085	0.11
1994	2211775	60053	4560	24152895	1960	0.1087	0.14
1993	2308890	84988	4600	25015175	1948	0.115	0.15
1992	2361235	45703	4480	23589013	1661	0.116	0.16
1991	2575655	144380	4640	24952225	1661	0.124	0.17
1990	2569463	83657	4560	24449268	1650	0.0915	0.14
1987	1973436	48933	4720	23316313	1706	0.076	0.13
1986	1745304	38918	4640	22882574	1628	0.0577	0.1
1985	1654353	98812	4400	22139686	1611	0.068	0.12
1984	1719679	51608	4160	21633846	1574	0.092	0.17
1983	1454865	13541	4160	20969609	1503		
1982	1240084	33209	4320	20835895	1406	0.073	0.15
1981	1240084	65460	4040	20517098	1406	0.069	0.15
1980	1136511	21596	3760	19614900	1386		
1977	691851	22589	3840	17430000	1687	0.0577	0.19
1976	645197	61193	3600	16859843	1322	0.0281	0.1
1975	617505	47348	3320	15693308	1275	0.026	0.1
1974	538741	29820	3080	15080031	1624	0.025	0.1
1973	404169	45616	3137	14742000	1126	0.0166	0.07
1972	370029	42289	3186	19113500	1071	0.0141	0.06
1970	239744	14710	2803	11430000	988		
1960	108360	1252	966	4110000	796	0.01553	0.1
1950	56364	5464	<400	1287200			
1944	21790	2667		644500			
1930	10658	1503		205100			
1920	4702	790					
1914	1124	390					
1913	10076	-494					

All statistics retrieved from assorted Municipal Light Department Reports located in Boylston Annual Reports from 1912 to 2005.

Appendix C: Street Abbreviations

Street Name	Street Code
Abbey Road	ABBEY_RD
Adams Street	ADAM_ST
Barney Road	BARNEY_RD
Bay Path Drive	BAYPAT_DR
Belair Street	BELAIR_ST
Birchwood Drive	BIRCHW_DR
Birdland Drive	BIRDLA_DR
Boulder Way	BOLDER_WY
Boylston Road	BOYLST_RD
Brooke Road	BROOKE_RD
Brookside Avenue	BROOKS_AV
Butler Road	BUTLER_RD
Carol Drive	CAROL_DR
Castaldi Drive	CASTAL_DR
Central Street	CENTRA_ST
Church Street	CHURCH_ST
Clark Street	CLARK_ST
Clearview Avenue	CLEARV_AV
Coderre Street	CODERR_ST
Columbus Road	COLUMB_RD
Cook Street	COOK_ST
Cross Street	CROSS_ST
Cutler Road	CUTLER_RD
Cynthia Drive	CYTHIA_DR
Dewey Avenue	DEWEY_AV
Diamond Hill Avenue	DIAHIL_RD
Duffy Road	DUFFY_RD
East Temple Street	ETEMPL_ST
Edgebrook Drive	EDGEBR_DR
Edgewood Street	EDGEWO_ST
Elmwood Place	ELMWOO_PL
Ethan Allen Drive	ETHALL_DR
Fariacre Drive	FAIRAC_DR
Flagg Street	FLAGG_ST
Fox Tail Way	FOXTAI_WY
French Drive	FRENCH_DR
Glazier Street	GLAZIE_ST
Green Street	GREEN_ST
Greenwood Street	GREENW_ST
Gulf Street	GULF_ST
Hall Pond Road	HALPON_RD
Harrington Circle	HARRIN_CR
Heritage Lane	HERITA_LN
Heywood Street	HEYWOO_ST
Highland Street	HIGHLA_ST
Hillside Avenue	HILLSI_AV
Hobson Avenue	HOBSON_AV
Intervale Street	INTERV_ST
Juniper Hill Road	JUNHIL_RD
Kendall Place	KENDAL_PL
Kendall Road	KENDAL_RD
Knob Cone Drive	KNOCON_DR
Larkin Road	LARKIN_RD
Ledgewood Drive	LEDGEW_DR
Linden Street	LINDEN_ST
Longfellow Way	LONGFE_WY
Longleaf Road	LONLEA_RD
Madera Court	MADERA_CT
Madison Avenue	MADISO_AV
Main Street	MAIN_ST
Main Street Circle	MAISTE_CR
Maple Way	MAPLE_WY
Maryanne Drive	MARANN_DR
Melrose Street	MELROS_ST
Midland Road	MIDLAN_RD
Mile Hill Road	MILHIL_RD
Miles Avenue	MILES_AV
Mill Road	MILL_RD
Mill Road Circle	MILROA_CR
Morningdale Avenue	MORNIN_AV
Nicholas Avenue	NICHOL_AV
Oakdale Street	OAKDAL_ST
Oak Hill Lane	OAKHIL_LN
Old Orchard Circle	OLDORC_CR
Oregon Avenue	OREGON_AV
Orient Street	ORIENT_ST
Paul Ware Drive	PLWARE_DR
Paul X Tivnan Drive	PAUXTI_DR
Pendell Circle	PENDAL_CR
Pine street	PINE_ST
Pleasant Lane	PLEASA_LN
Poe Avenue	POE_AV
Reservoir Street	RESERV_ST
Rocky Pond Road	ROCPON_RD
Roseberry Drive	ROSEBE_DR
Sanatorium Road	SANATO_RD
Scar Hill Road	SCAHIL_RD
School Street	SCHOOL_ST
Sewall Street	SEWALL_ST
Shrewsbury Street	SHREWS_ST
Smallwood Circle	SMALLW_CR
Smith Road	SMITH_RD
Stark Terrace	STARK_TE
Stiles Road	STILES_RD
Stockton Street	STOCHT_ST
Strawberry Lane	STRAWN_LN
Sylvan Lane	SYLVAN_LN
Temple Street	TEMPLE_ST
Tower Hill Road	TOWHIL_RD
Twin Springs Drive	TWISPR_DR
Underwood Avenue	UNDERW_AV
Upland Road	UPLAND_RD
Warren Street	WARREN_ST
West Boylston Street	WESBOY_ST
West Temple Street	WTEMPL_ST
Willow Road	WILLOW_RD
Willard Andrews Road	WILAND_RD
Woodland Drive	WOODLA_DR