FY06 NATSRL_Integration of Automated Vehicle System Data Acquisition into Fleet Management

Final Report

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Executive Summary

Fleet management is central to the activities of the Minnesota Department of Transportation (Mn/DOT). With population growth, increases in vehicle ownership, and a growing number of budget constraints, fleet managers must devise methods of detecting and resolving cost sinks while improving the ability of the department to meet and exceed expected service levels.

This project aims to provide fleet managers with required tools for efficient and effective control of fleet resources by integrating automated vehicle system data acquisition into fleet management. The result of a series of fleet management improvement projects, this project is one of many on which Mn/DOT has collaborated with the Northland Advanced Transportation Systems Research Laboratories (NATSRL) at the University of Minnesota Duluth. Previous projects include "Benchmarking analysis of fleet performance and maintenance," and "Fleet life cycle costing with intelligent vehicles."

An important consideration in typical return on investment situations is the optimal life span of an asset. The same holds true in the management of Mn/DOT's fleet and was the subject of the Life Cycle Costing project by Wyrick and Sivanich in 2005. This determination requires the availability of good operations data and associated costs. A lack of good data highlighted the need for automation.

The automation process was designed and and a trial was designed and conducted using wireless radio modems to transmit information from the snowplow to Mn/DOT databases. Proprietary restrictions limited the effect of this system. In order to use the wireless modems to transfer data from the on-board engine computer to a receiver inside a maintenance station, a third party software system is required. These systems actually transfer data through the vendor's computer server, which can then be accessed by a client via the world wide web.

As Mn/DOT was reluctant to have these data transferred through the computer of an outside entity, other options for automation were explored and recommendations were made for the improvement of the current data acquisition process to match alternative management strategies.

1. Introduction

"Equipping fleet managers with tools for efficiency, [and optimal] productivity, is the final goal for continuous improvement in fleet management within DOTs" (Bergoffen, 1992; Storhaug, 2003). This project aims to provide knowledge and tools that would enable the Minnesota Department of Transportation (Mn/DOT) more efficiently control its resources and improve productivity at Mn/DOT through the integration of automated data acquisition into its fleet asset management system.

Asset management involves cost effective maintenance, upgrading, and operating of of physical items to which an organization lays claim. It requires engineering, business and economic principles and "provides a framework for handling short-and long-range planning" (Sivanich 2004, FHWA, 1996). The effectiveness of these planning decisions depends on access to timely and accurate operations data. This, of effectively managing assets, is described by Osborne (2001) as an important driver of an organization's success.

Mn/DOT controls over 3,000 pieces of equipment. This includes about 809 snowplows, over 400 mid-sized trucks, and other vehicles (Baldwin, 2007). With increasing budgetary constraints and service requirements, it is required that fleet managers, including those at Mn/DOT, optimize fleet utilization ("APQC" 2003) through the implementation of management practices that maximize fleet utilization while effectively engaging in predictive maintenance practices. In addition, fleet managers must be capable of determining optimum fleet life cycles – points at which the cost of maintenance exceed the benefits derived from vehicle operation – through analysis of recent, reliable data.

The automated data acquisition project is one of a series of fleet management improvement projects on which Mn/DOT has collaborated with the Northland Advanced Transportation Systems Research Laboratories (NATSRL), at the University of Minnesota Duluth. Previous projects include "Benchmarking analysis of fleet performance and maintenance," and "Fleet life cycle costing with intelligent vehicles."

In the benchmarking analysis project, Wyrick and Storhaug (2003) devised a needs hierarchy at Mn/DOT using quality measures like cause and effect analysis. Through surveys, best public and private sector practices were determined with regards to cost savings, and organizational and policy issues. Practices at Mn/DOT were found to be on par with the average Department of Transportation (DOT).

From surveys of state DOTs in Arizona, Oregon, Maine, New York and Michigan, among others, Wyrick and Storhaug (July 2003) discovered that DOTs with higher numbers of non-redundant fleet management measures tended to fare better than those with fewer, or many redundant, measures.

Previous work by Huff, Mariucci, Uecke, and Zabel (2002) was performed as the Road Runners Research Group, a senior engineering design team at the University of Minnesota Duluth. They made recommendations for a move from preventive vehicle maintenance that was based on mileage and hours of operation, to predictive maintenance practices, in which vehicle operational trends are monitored for determination (prediction) of possible failures. They noted that implementation of wireless capabilities will enhance the ability to obtain frequent updates. At the time, Mn/DOT used the ThomTech Design and Maximus M4 databases to collect information from the truck and store collected operational data for fleet management purposes. Three important decisions for fleet managers include (1) the determination of appropriate maintenance processes; (2) timing of said activities; and (3) scheduling of follow-up inspections. This study aims to provide tools that could aid Mn/DOT personnel in making these decisions by increasing data currency.

An area recommended for further research in conclusion to the benchmarking study was the cost of extending equipment life beyond determined optimal life cycles. The optimal life cycle for a given asset is referred to as the point in the life of an asset at which the cost of ownership is minimum (Erquicia and Wyrick, 2005). Life cycle costing analyses for snowplows were carried out in 2003-04 by Wyrick, Dhruv and Sivanich. They analyzed the following cost elements:

- **Purchase Price**: … the cost of purchasing the vehicle (chassis) plus the cost of all of the ancillary equipment (such as plows and sanders). The purchase price data were extracted from the M IV information system.
- **Maintenance Costs**: … maintenance costs play a large role in the LCC analysis. For this study, the maintenance cost is composed of three separate cost elements. These elements are Shop Labor, Field Labor, and Parts

- **Fuel Expense**: … can be a large cost in the LCC of a vehicle. This can especially be the case when the vehicle is large and is used to haul heavy loads of material.
- **Salvage Value**: The vehicle salvage value is the dollar amount that Mn/DOT can expect to receive when the unit can be sold. … In the cost breakdown of a snowplow owned and operated by a government agency, the salvage value represents the only positive cash flow in the life cycle of the plow.
- **Discount Factor**: When conducting an economic analysis with an evaluation period of more than one year, it is necessary to take into account the time value of money (FHWA, 2003). The buying power of the dollar in year zero is not equal to the buying power in year ten. In order to equate cash flows in the base year (year zero) to future cash flows, a discount factor must be applied. Application of the discount factor brings the cash flow in question back to the base year, resulting in the present value of the cash flow.

  Choosing the proper discount factor for the LCC analysis is essential for producing accurate results. Mn/DOT's recommendation towards the value of the discount factor was a 5% annual discount rate. This value falls in line with the recommendations of the FHWA. According to that agency, the discount factor for conducting a LCC analysis should be within the range of 3%-5%. Thus, 5% was selected for the study.

(Sivanich, 2004)

Recommendations were made, using results of analysis of the effect on maintenance costs and salvage value, among other variables, for each additional year of operation. Optimal values of 8 and 12 years were derived for Districts 1 and 6, respectively (Wyrick, Dhruv and Sivanich, 2004). These findings were based on work carried out on class 330 and 350 single and dual axle snowplows in Districts 1 and 6. An assumption made on this project was that all the Mn/DOT fleet had equal utilization levels and maintenance schedules. This coupled with poor data quality, prompted recommendations for automation of the data collection process.

Further study by Erquicia and Wyrick (2005) attempted to expand LCC activities to more vehicle classes (of sedans and trucks) and to conduct studies for application in all Mn/DOT districts. The equivalent uniform annual cost (EUAC) amortized costing method was used in evenly distributing the present worth of future expenditure over entire fleet life cycles. This was chosen over the present worth model, which becomes invalid for expenses accrued in non-simultaneous time periods. To provide the most realistic model, LCC calculations were made using double declining depreciation. With an increase in optimal life cycles by about six years in Districts 1 and 6, this project made improvements to the result of previous work.

A major reason for this discrepancy was the decision to perform analysis on fleet using aggregated data. Previous regression analysis had been carried out on a unit basis and was prone to fluctuations based on rare and unlikely occurrences like windshield breakage, and other such occurrences. This (piecewise cost consideration) generated exponential cost trends and thus lower optimal life cycles, as the model was more sensitive to peculiar events. While these are logical reasons for possible discrepancies, life cycle recommendations made have been compromised by the quality of available data. When this project was conducted, the M4 management information system had recently been introduced. Historical information was, thus, limited to about four years.

An additional discovery of the life cycle costing projects (Sivanich and Wyrick [2004] and Erquicia and Wyrick [2005]) was the poor quality of data on fuel consumption and expense. Cases of the allocation of uncharacteristically high fuel expense to underutilized vehicles or zero fuel expenditure for vehicles with high utilization levels were noted during these studies. This was partially attributed to snowplow drivers' billing practices; specifically, charging refill costs for several trucks to a single card.

Problems with the system for mileage data entry to M4 (predecessor to the current M5 system) were also discovered. There were no checks to ensure logical progression of mileage data entry. As such, Erquicia and Wyrick (2005) reported cases in which vehicles "traveled" over 100,000 miles in a single month, while other vehicles reported no mileage traveled within said month. In most cases, the truck with the abnormally high mileage would have no miles recorded for subsequent months as the database did not accept values less than the previous entry. Thus, all subsequent entries were logged as zeroes and would remain so until a value higher than the abnormal entry, say 100,000 miles, was entered.

The desirability of a system to reduce human involvement and error became evident and recommendations were made to that effect. The current project is a continuation of this line of research and focuses on the automation of the data collection process.

Project Objectives

To serve as a measure of progress and eventual project success, a set of objectives was developed at the onset of the project. The overriding objective was the improvement of the efficiency of data acquisition practices through the elimination of error in the entry of data on operations of Mn/DOT's class 330 and 350 snowplows. This was to be carried out through automation and reduction of human error, or human interaction entirely.

The objectives and requirements for the automation of the data acquisition process included the following:

- Identification of vehicle information requirements for fleet management and life cycle costing decisions.
- Comprehension of the requirements, capacities, and limitations of the automated vehicle systems data acquisition.
- An understanding of the data acquisition interface of M5, especially the requirements, capacities, and limitations of wireless technologies.
- Identification of the gaps in capabilities between the potential use with the M5 system and the current infrastructure, including hardware, software, and human issues.
- Integration of life cycle considerations and performance measures into designing an automated vehicle data acquisition system.
- Recommendation of alternatives to Mn/DOT for a prototype demonstration in District 1.
- Communication of final results of this research to Mn/DOT to provide effective organizational learning for implementation across the state.
- Submission of at least one article summarizing fleet management research for publication in transportation engineering and quality/engineering management journals.

Through the achievement and implementation of project objectives, Mn/DOT can realize savings in fleet maintenance costs and optimize snowplow utility through determination of optimal replacement points.

In addition, recent state government cost cutting measures have prompted discussion, between government agencies, on efficient methods of equipment utilization. From discussions in St. Paul, Minnesota, with John Scharfbillig (Mn/DOT Fleet Manager, 22 January 2007), Mn/DOT will likely begin seasonal rotation of vehicles and equipment with other state agencies. The department of transportation will require methods of diagnosing problems on vehicles that are not physically available for maintenance check-ups.

Keene (2000), lists nice central key areas of fleet management as discussed by Storhaug (2003). They are outlined below.

1. Preventive and predictive maintenance
2. Computerized work management
3. Clear bid specifications
4. Highly skilled, trained, and certified personnel
5. In-house warranty repairs
6. Parts management
7. Support equipment and facilities
8. Outsourcing of appropriate activities
9. Customer orientation with courteous service

Preventive and predictive maintenance practices at Mn/DOT are the subject of a senior design report by Kelly Huff, Annie Mariucci, Alison Uecke, and Jay Zabel (2002). Preventive maintenance advocates inspection according to pre-determined time intervals – usually by the manufacturer – while predictive maintenance calls for a more proactive approach. It involves the use of analytical tools and frequent tests, including vibration analysis, infrared thermograph, thermo sensing, ultrasonic detection, et cetera (Keene 2000; Storhaug 2003). As is shown later in this report, a move to predictive maintenance is increasingly advocated as the costs associated with the increase in failure frequency, due to higher demand and budget constraints, necessitate proactive inspection and maintenance measures.

The availability of historical data is necessary for accurate failure forecasting and for the scheduling of optimum inspection and maintenance events. Computerized work management allows for the collection and storage of said data.

Clear bid specifications serve to ensure quality standardization across an organization's fleet. They serve to reassure drivers of the high standards to which equipment suppliers are held. In addition, employee training and certification guarantees that the expectations of the general public are being met with regard to fleet and driver proficiency.

Repairs and parts management can be outsourced to certified contractors. Storhaug (2003) argues for the inclusion of "safety issues" to the list of important areas of fleet management. This report focuses on methods for satisfying the first key area; preventive and predictive maintenance; through the consideration of automated data acquisition systems that minimize errors in data collection.

Constraints and Limitations

Prior to the onset of this project, the Minnesota Department of Transportation had used several databases for collection of maintenance and snowplow operations data. The Thom Tech data acquisition system, by Thom Tech Design, stores collected data on the truck. The FleetFocus™ M5 database, designed by Maximus Asset Solutions, is then manually fed the data from the Thom Tech system (Figure 1). It was, thus, highly desirable that the devised solution utilize both databases, as the introduction of a new, common, database would incur prohibitive procurement and set-up costs.

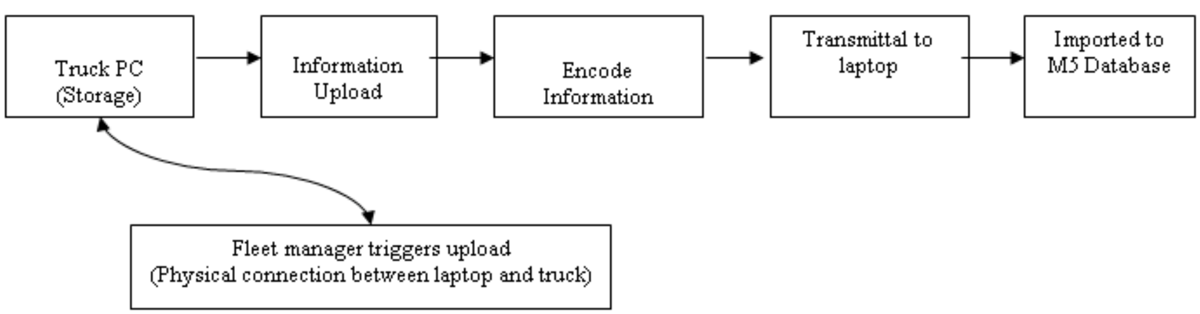

Figure 1-1 Current data acquisition process

In addition, communication systems must be compatible with manufacturer-specific software and devices, as Mn/DOT purchases snowplows from a number of manufacturers. Each manufacturer designs proprietary data collection software and transfer codes that are obtained solely from the manufacturer in question.

Project Approach

The original intent of this work was to improve the quality of data used in determining the economic life cycle for assets. These data included receipts for fuel and consumables, which are purchased on the road, odometer readings and other items that are transcribed into the appropriate costing database.

The project was delayed when no graduate student was available to work as a research assistant in the fall of 2005. A senior design team and one graduate research assistant (GRA) worked on the project to help define it in spring 2006, but it was not until the current graduate student arrived in 2006 – 07 that consistent work would take place.

From discussions with Mn/DOT personnel, relevant fleet operation information was identified for transfer by the automatic data acquisition system from the vehicles to the Mn/DOT databases. From one such meeting with Robert Ellingsworth, John Scharffbillig, and Randy Cameron (22 January 2007), it was determined that data be collected on the following:

- Vehicle mileage
- Fault codes
- Hours of operation
- Fuel consumption rate

Onboard computer systems, in most cases, store this information for retrieval by hard wired connections upon return to a base station. Previous work on life cycle costing revealed considerable error in the collection of data on fuel consumption and odometer readings. By automating the data transfer process, this project aims to provide Mn/DOT with accurate and current information that would facilitate fleet management and life cycle decisions. The approach taken then was to try to identify methods of interfacing with the onboard engine computer and the Mn/DOT computers using wireless technology.

By January 2007, many of the "routine" activities of fueling and properly documenting receipts were being correctly input into the costing systems, so these considerations became less important over time.

Report Organization

This first chapter has reviewed the evolution of the need for automated data acquisition at Mn/DOT that has resulted from previous work in life cycle costing of fleet assets. The objectives of the research have been presented.

The methodology used in this research will be described in Chapter 2, and are laid out in accordance with the originally proposed project tasks. The process of evaluation used in determining wireless needs, potential application, an testing are presented.

Chapter 3 discusses the actual performance of the methodology presented in Chapter 2. Chapter 3 further discusses problems encountered and results. This is of high importance as the testing/evaluation process will demonstrate the compatibility, or lack thereof, between the recommended solution, on-board engine computers, and Mn/DOT's databases.

Alternative courses of action are presented in Chapter 4. This chapter includes alternatives, recommendations, conclusions from this research, and suggestions for future research.

More information on the wireless modems used in this research are contained in the Appendix.

2. Methodology

This chapter describes the methodology used in this research. From the proposal for this study, a number of tasks were specified to serve as guides for research activities. These include:

1. Literature Review.
2. Evaluate information to be automatically collected from vehicles for fleet management and life cycle costing decisions.
3. Understand the evolution in the capabilities, requirements, and limitations of automated vehicle system data acquisition.
4. Investigate the capabilities, requirements, and limitations of the M5 information system regarding automated data acquisition, especially with wireless capabilities.
5. Identify gaps in overall system performance and potential improvements.
6. Recommend alternatives to Mn/DOT for a prototype wireless automated vehicle system data system at a Mn/DOT facility in District 1.
7. Prepare presentations, reports and articles.

A report detailing results and recommendations from work carried out on the first four tasks was prepared in the spring of 2006 by HHC Consulting, a group of senior mechanical and industrial engineering students at the University of Minnesota Duluth (Carlson, Hakala, and Hovde). Their findings and recommendations are summarized and updated in this report. Also included are details of work completed by UMD engineering management graduate research assistants Chinweike Eseonu and Hilal Katmale.

Task 1: Literature Review

A review of previous work was carried out in order to ensure adequate understanding of current practices and theory, ensure currency of research, and to determine areas for improvement as well as feasible methods for implementation at Mn/DOT.

The review included past project reports from the benchmarking, life cycle costing, and early parts of the current project. Trade journals and other such publications were consulted to determine the current state of practice. In addition recent innovations in the fleet management were studied through consultation of fleet managers at trucking and other transportation firms.

Task 2: Evaluate information to be collected automatically

This section was aimed at the identification of data sets of highest importance to the decision making process. Said data was primarily determined through a baseline analysis of the data that was recorded on-board and discussions with Mn/DOT personnel. Automated data collection was to be governed by the feasibility, importance and frequency of use of data points in fleet management decisions.

Specifications for the final acquisition system were determined through analysis of the current Mn/DOT process. Alternatives were then considered against these criteria. The most viable alternative was tested for implementation on snowplows in Duluth and gradual application to plows in other regions.

Task 3: Understand the evolution in capabilities, requirements, and limitations of automated vehicle system data acquisition

This task was satisfied through the creation of process maps for the current data collection process at Mn/DOT, determination of steps for possible elimination through the introduction of wireless transfer. Changes in database capabilities, ongoing research into automated data acquisition and its limitations were also studied.

This was aimed at facilitating the determination of appropriate levels of automation to be implemented and the timing of said implementation. Discussions with Mn/DOT staff in Duluth and St. Paul painted a clearer picture of current challenges and desired results.

Task 4: Investigate the capabilities, requirements, and limitations of the M5 information system regarding automated data acquisition and anticipated goals

This involved taking an inventory of the M5 system, its capabilities and specifications, and comparing these to the devices available for effecting wireless transfer, like the Thom Tech system which was previously in use at Mn/DOT. Discussion with Mn/DOT personnel in St. Paul provided. This task focused on reducing the occurrence of bad data by exploiting advertised wireless capabilities of the M5 system. Manual data entry from written documents had previously led to incorrect billing pairings between activities and assets. Vehicle requirements were determined and methods of standardization were considered.

Task 5: Identify gaps in overall system performance and potential improvements

Process maps comparing the original situation to the desired outcome showed differences between hard wired and wireless connections and were used in determining areas for potential improvement. A number of options were considered for "bridging the gap" between the "current" and "desired" situations. The capabilities of M5 and the automated data acquisition system, and variants thereof, were evaluated.

Task 6: Recommend Alternatives to Mn/DOT for a prototype wireless automated vehicle data system at a Mn/DOT facility in District 1

Comparison of alternate wireless systems was undertaken to determine prototype wireless data collection systems for Mn/DOT facilities in District 1, located in northeastern Minnesota. Consideration was given to alternatives including maintenance of the status quo, the use of external agencies and the creation of a Mn/DOT proprietary data acquisition system among other options. The pros and cons of each option were discussed before arrival at the chosen solution.

Task 7: Prepare presentations, reports and articles

Throughout the preparation and undertaking of this project, presentations, reports, and articles were prepared to satisfy reporting requirements and provide the knowledge gained and lessons learned to a wider audience.

3. Results and Discussion

This chapter describes the results from the methodology used in this research. This follows the format used in the previous chapter, which proceeds from task to task.

Task 1: Literature Review

A review of sources was conducted to determine the current "state of art," which refers to the most recent innovations in the area of automated data acquisition for fleet management. The current "state of practice" can be considered to what practitioners are actually using on a fairly wide basis. In determining the current state of practice, trucking companies and other state DOTs were contacted. Over 50 percent of the companies contacted – including Atlas Van Lines, Halvor Lines, and Target Corporation – use combinations of real time data acquisition software devised by Qualcomm or PeopleNet (two prominent companies providing information services for fleet management), or other combinations of proprietary methods. It was necessary to make this distinction – between "state of the art" and "state of practice" – in order to determine the potential for implementation at Mn/DOT.

A review of previous research on benchmarking by Wyrick and Storhaug (2003), academic journals, Mn/DOT reports, trade magazines and online publications was performed in order to determine of states of art and practice.

Mn/DOT Reports:

Benchmarking Fleet Management by Wyrick and Storhaug (2003) studied fleet management practices at several departments of transportation, including Mn/DOT. They compared record taking on cost issues including vehicle cost per mile per hour, actual operating costs versus budgeted costs, and the like. Research was also carried out on policy practices and organizational structure in order to spot correlations between levels of these practices and effective fleet management. The aim, here, was to determine best practices in fleet management. It was discovered that fleet management policies in private firms were similar to those at DOTs. Best practices from private firms and other DOTs could, thus, be adapted for use in management of the Mn/DOT fleet.

The report by the Road Runners Research Group (Huff, Mariucci, Uecke, and Zabel, 2002) was aimed at determining "alternate methods of dealing with snowplow vehicle breakdowns." The team investigated methods of implementing Total Productive Maintenance at Mn/DOT to involve a shift from reactive maintenance to preventive maintenance, and from preventive to predictive maintenance practices aimed at attaining a zero breakdown maintenance system. Figure 3-1 shows the graphical representation, created by the Road Runners team, of maintenance scheduling scenarios and the corresponding costs incurred. In order to ensure vehicle operations data accuracy and prevent "run to failure," the team recommended the introduction of automated data acquisition systems to ensure frequent and consistent reporting of operations data. It would further increase the benefits of such a system if it were capable of highlighting and reporting possible faults, as discussed with Mn/DOT personnel in St Paul.

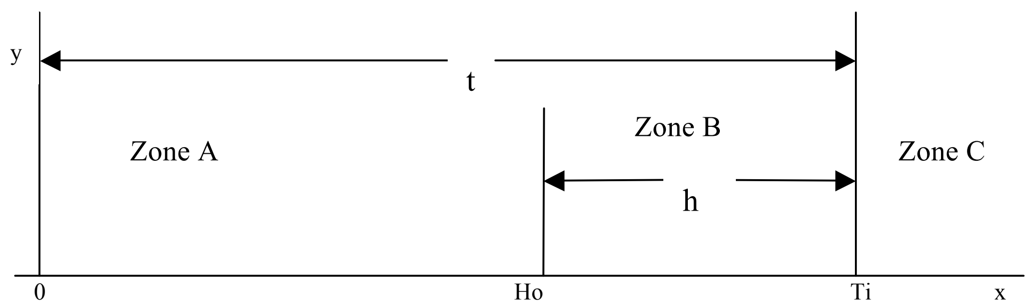

Figure 3-1 Maintenance/inspection scheduling scenarios: effect on maintenance expense

Source: (Huff, Mariucci, Uecke and Zabel, 2002)

Where

t = time

T_i = Time of inspection

H_0 = Inspection point (time) at which the cost of an impending failure is prevented

Inspection in Zone A is considered sub-optimal as inspection costs are incurred without savings on "run-to-failure." This is characteristic of most high frequency preventive maintenance practices. Zone B represents preventative maintenance practices and is also known as the “lapse zone” (Huff et. al, 2002). In this region, the cost of an inspection prevents machine failure and is, thus, optimal. Zone C is equivalent to “run-to-failure” and is the least desirable option.

Online Trade Magazines and Freight/Trucking Company Contacts:

Discussions with trucking companies and subscriptions to online trade magazines including *Fleet Owners' Newsline*, *Logistics Management*, and *InfoTech Newsletter*, provided information on the current “state of practice.” Information on devices like “Fleethawk” by Skytel, PeopleNet’s Web-based fleet management interface, and Qualcomm’s “Omni Vision, Omni Tracs and Omni Express systems” (www.qualcomm.com) were discovered through a review of these weekly publications. Qualcomm’s family of mobile computing platforms uses a nationwide satellite link to transfer information between truck drivers and home bases. Vehicle location, operations reports, and text communication can be sent using this system (Parry, 2002 & Qualcomm website). Like OmniTRACS, FleetHawk uses an onboard transceiver to monitor driving patterns, vehicle location, and operations data (FleetOwner, May 1, 2004). This information is then uploaded to Skytel’s database and can be viewed online by the fleet manager (Skytel Website, 2006). PeopleNet also uses two-way communications from the truck and driver to the fleet manager via PeopleNet’s database. With this system, there is the possibility of integration with Mn/DOT’s databases (PeopleNet Website and FleetOwner, December 1, 2006).

These also provided insight into “state of the art” innovations like Michelin’s redesigned eTire pressure and asset monitoring system (eTire II), which uses a wireless, battery-free sensor to provide temperature compensated tire pressure measurement to reduce vehicle breakdowns due to deflated tires by identifying slow leaks. The sensor is powered by surface acoustic waves (SAW) and is glued inside the tire wall. It is capable of transmitting data (tire identification and pressure data) to handheld devices and drive-by readers (Michelin, 2006). Tire replacements are one of Mn/DOT’s largest expense areas (Kerry Monson, Duluth repair shop supervisor), so this could be an area of future investigation.

Personal Interviews

Interviews were conducted with Mn/DOT personnel; Target Corp.'s Minnesota Regional Transportation Supervisor, Marcus Ebenhoch; Qualcomm, Halvor Lines and Atlas Van Lines personnel; Pam Enrici of the University of Minnesota Duluth Library; and Dr. Eil Kwon, Director of NATSRL. Ebenhoch provided information on the state of practice at Target, a company that utilizes a complex supply chain to deliver goods to stores across the country and requires an effective fleet monitoring system. Web based Qualcomm GPS systems are used at Target, Halvor Lines and Atlas Van Lines. These systems require direct data uploads to Qualcomm's database, from where fleet managers can retrieve data as required. Wide industrial use makes the Qualcomm Omni Tracs system a viable alternative for use at Mn/DOT.

Task 2: Evaluate information to be collected automatically

Life cycle costing decisions were central to the determination of data to be transferred automatically. The idea here was to reduce the amount of information that has to be manually entered into the M5 system. In addition to operational parameters requested by Mn/DOT personnel, consideration of the effect of human error in data entry on maintenance scheduling, effective vehicle repairs, and cost control processes drove the selection process.

In addition, life cycle costing research that had been conducted by the TriForce Consulting mechanical and industrial engineering senior design team in 2004 (Hartman, Wagner, and Dorau) was reviewed. Discussions with Mn/DOT personnel showed that a satisfactory method had already been devised for entering some of the required data like shop and field labor, and part consumption, into M5. Their focus was thus concentrated on automating the transfer of fuel consumption data.

Carlson, Hakala, and Hovde of the 2005 HHC Auto Solutions UMD mechanical and industrial engineering senior design team considered the expenses of fuel consumption, equipment depreciation, costs associated with vehicle mileage/odometer readings, shop labor, parts replacement, and field labor. Because shop labor, parts replacement, and field labor were already included in the database with acceptable quality levels, they decided to focus on the automation of the fuel expense recording process. The current method requires that the driver record odometer readings at each fuelling event. This information is then transferred to the M5 database via the WEX (Wright Express) Company.

Harsh winter conditions during snowstorms can be very stressful, which may impair an operator's ability to always make accurate vehicle mileage entries. In addition, vehicle specific fuel cards could be used to purchase refills for more than one truck. While plow drivers would consider this a better method of improving snowplowing efficiency, as other plow drivers return to road clearing duties while the payee covers the fuel charges, this practice impairs effective life cycle costing analysis. It has been decided that Mn/DOT will continue the use of WEX cards, but will require automation of data collection on the rate of fuel consumption. Discussions with Mn/DOT personnel highlighted the following areas for further consideration:

- Fuel consumption
- Mileage/Odometer readings
- Fault codes
- Hours of operation

Task 3: Understand the evolution in capabilities, requirements, and limitations of automated vehicle system data acquisition

An understanding of the current "state of art" was necessary to determine possible alternatives for implementation at Mn/DOT. It was also necessary that the current industry standards and practices be understood to allow for adaptation of recent innovations to best suit, or upgrade, the current "state of practice."

The HHC Auto Solutions project team evaluated levels of automatic data acquisition at Mn/DOT locations in Virginia, Mankato and Duluth and devised Figure 3-2 to describe the transfer of maintenance and operational data at the District 1 offices in Duluth. The team has indicated steps for automation, including wireless uploading of mileage and ID number at each fuelling event is desirable, as shown in Figure 3-2.

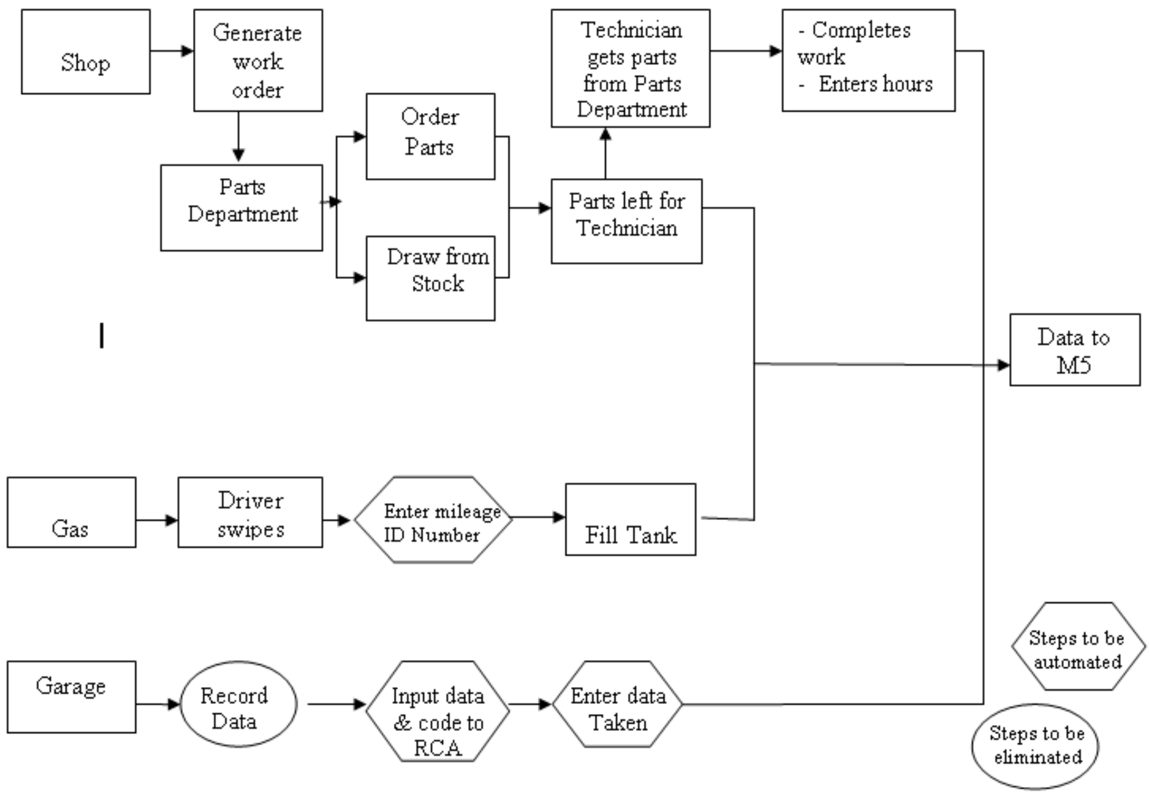

Figure 3-2 Precious data acquisition process at Mn/DOT District 1 Duluth Terminal

Source: (Carlson, Hakala and Hovde, 2006)

From discussions with Mn/DOT personnel (Kerry Monson and John Scharffbillig) and review of reports presented by senior design teams, it was learned that Mn/DOT locations in Virginia and Mankato are engaging in automated data acquisition projects of their own. It was decided, by previous and current researchers, that discussions with personnel in said locations would prove valuable to the implementation of data collection automation in Duluth.

The increasing move toward the use of intelligent vehicles defines the state of practice. The trend is towards vehicles that acquire, process, and respond to environmental conditions or other data. With regard to Mn/DOT specific systems, the integration of M5 with external data acquisitions systems, like those of Qualcomm, are currently being explored.

Task 4: Investigate the capabilities, requirements, and limitations of the M5 information system regarding automated data acquisition and anticipated goals

In addition to the determination of capabilities, requirements and limitations of the M5 database in the automatic acquisition of vehicle operational data, research teams investigated the capabilities of other Mn/DOT databases, including Resource Consumption Allocation (RCA), Work Maintenance System (WMS), and ThomTech. Apart from the RCA and WMS databases, each of the Mn/DOT databases operates independently. It was agreed, after a review of IEEE codes and standards and interviews with Mn/DOT personnel and Electrical Engineering professors at UMD, that while database integration would increase cost effectiveness and fleet management efficiency, the level of coding required would necessitate considerable experience in software engineering. Focus was thus shifted to the capabilities of each system and to gaining an understanding of the data transfer within the Mn/DOT database network. This, it was assumed, would reveal likely points of data contamination and allow for better precision in reducing the occurrence of "bad data" (Katmale and Wyrick, 2006).

Capabilities and Requirements

The ThomTech system utilized onboard data acquisition devices that records data on air and curb temperature, plow position, rate and quantity of salt/sand usage, among other data sets. Created by ThomTech Design, Inc., the data were stored on an onboard computer, with relevant data sets – like salt/sand consumption – made available to the driver in real time. Where re-routing could become necessary, the availability of data on salt and fuel levels in plows to be re-routed, would be useful in making necessary decisions.

An improvement to the conditions noted during work on the life cycle costing projects, is the ability of the new M5 system to ensure logical data entry. In other words, problems with bogus mileage values should no longer occur.

The M5 system is used in generating work orders, and in recording and reporting parts usage and maintenance events. It is, thus, desirable that the M5 database be capable of interfacing with other databases and with manufacturer software. This would serve as a verification process to reduce the entry of bad data, which ultimately compromise fleet management decisions. It is possible to use M5 in automated data acquisition, according to Maximus Inc.'s National Accounts Representative Barry Johnson (February 26, 2007). Results from ongoing tests at Schneider National Trucking and Logistics Company would verify this. Maximus Inc. is working with Schneider and Qualcomm to allow for AVL and mileage data transfer from Qualcomm's web portal to M5.

The Work Management Planning System is used in managing highway maintenance activities. As was discovered by The Road Runners Research Group, from interviews with Dawn Gustafson of the Michigan Department of Transportation (MDOT), frequent road maintenance events and quality monitoring can extend optimal life cycles by reducing snowplow damage due to loose debris and vehicle wear due to vibration (Huff, Mariucci, Uecke and Zabel, Spring 2002). Incorporating road maintenance records into vehicle operations data would provide fleet managers with trends for, or against, the MDOT assertion and allow for concentration on cost effective maintenance practices in areas where these measures have notable effects on the "bottom line."

Limitations

Lack of an interface between the databases has meant that optimal maintenance scheduling, as depicted in Figure 3-1, and effective life cycle costing have been compromised by the bad data. The TriForce Consulting senior design team (Hartman, Wagner, and Dorau, 2004) discovered, in attempts to obtain data for life cycle costing, that the Minnesota Accounting and Procurement System (MAPS) was more reliable as it contained more complete data that pre-existed the M4 system (predecessor to the M5 database). An effective solution to the problems resultant of the lack of verification for data entered on a database would be a cross-link between databases, or a central database.

Task 5: Identify gaps in overall system performance and potential improvements

In order to resolve the problems with data quality brought to light by Wyrick and Sivanich (2004), it is desirable that the data entry process for variables pertinent to life cycle costing analysis be fully automated. Full automation, though ideal, could prove problematic to implement. A survey conducted by the Fleetrio Consulting UMD senior mechanical and industrial engineering design team (Cirilli, Marksteiner, and Trainor, 2005) showed a 76% aversion to automated data collection among District 1 snowplow drivers. It was explained that the snowplow operators wished to retain active control of plow operations.

In District 1, the ThomTech automated data acquisition system had been implemented in the Virginia, Minnesota, subdistrict in 2005. Real time, wireless, data uploads were hindered by the magnetic field created by local minerals and terrain; cellular and digital signals were also intermittent. In addition, inability, according to interviews conducted by HHC Auto Solutions (2006), to utilize local police backup frequencies necessitated modifications to the ideal, real-time, data upload system. A batch system was created by Mn/DOT personnel. Operations data is uploaded to an onboard storage device in 12 second intervals and is then transferred to Mn/DOT databases upon return to the local base office. As was stated in the HCC project report, this system, though less than the ideal scenario of real-time wireless uploads, allows for report generation and effective maintenance scheduling – in accordance with recommendations put forward by the Road Runners Research Group for a move towards predictive maintenance practices as depicted in Figure 3-1.

The Duluth office uses minimal automation in data entry to the M5 or resource consumption and allocation databases. As with all other locations, the use of vehicle specific fuel cards allows for automatic data transfer via the WEX system. The manual entry of odometer readings, however, could compromise data quality, as snowplow operating conditions are less than optimal for accurate number memorization and repetition.

It has been the case that, in a bid to minimize the time between snowfall and plowing, one plow driver pays for fuel collected by other drivers who have returned to their routes (in a bid to optimize performance). In life cycle costing analysis, the picture becomes one of some “highly fuel-efficient” trucks and others with incredibly poor fuel economy.

As was indicated in the discussion of Task 2, automation of data entry for labor and parts consumption will not be automated at present. Compatibility issues between Mn/DOT's databases necessitate that each system work independently of the other. This is a shortfall from an ideal situation in which operations and maintenance data are stored in a single, or in compatible, database(s) and can be pulled up to create a single report, or schedule maintenance, for any vehicle. The Virginia solution provides an option for implementation in Duluth. Figure 3-3 depicts the data transfer process to be implemented at the Duluth office. Data are currently collected by and stored on manufacturer-specific onboard computers. This system would place transmitter modems on the trucks, which would communicate with receivers at Mn/DOT bases. Upon return to a Mn/DOT station, contact with the receiving modem would trigger a data upload from the engine computers. Where security considerations require, the data would then be encoded for transfer to Mn/DOT databases such as M5.

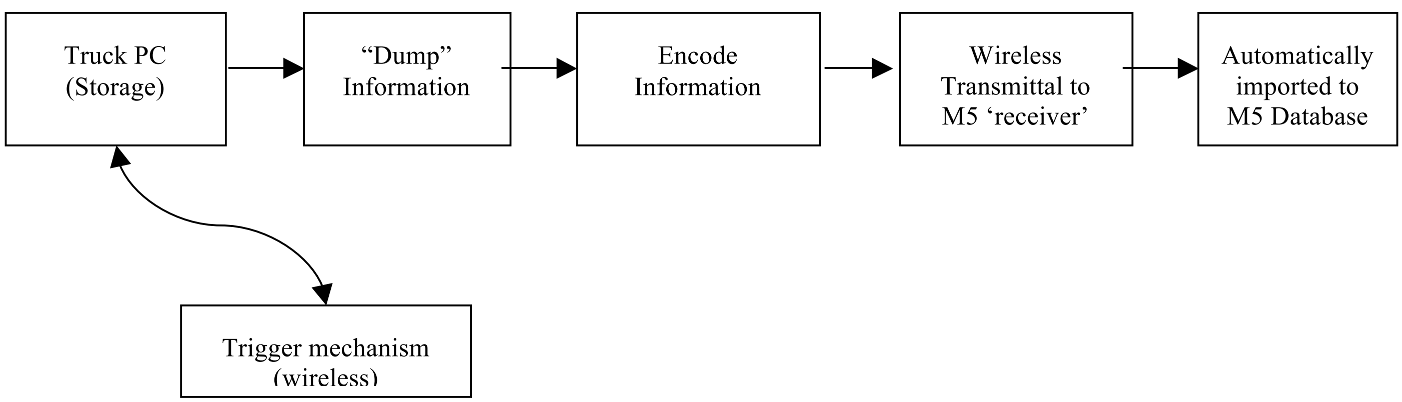

Figure 3-3 Desired Automated Data Transfer Process

Task 6: Recommend Alternatives to Mn/DOT for a prototype wireless automated vehicle data system at a Mn/DOT facility in District 1.

The State of Minnesota is considering several cost minimization methods, one of which is the pooling of fleet among departments within the state (Scharffbillig, 2007). It is, thus, highly desirable that Mn/DOT be capable of uploading operations information from its trucks during periods of use by other state departments.

In addition to the data acquisition systems evaluated by HHC Auto Solutions, which include Dossier Onboard, Discrete Wireless, and ThomTech Design systems, it has become necessary to find systems capable of carrying out required data transfer using well established, reliable communication networks. Dossier Onboard automatically collects vehicle operations data and warns drivers and fleet managers of maintenance and other operations issues (Mele, 2004). Discrete wireless provides a real time GPS tracking system with web based access for fleet managers. It allows monitoring of driving patterns, vehicle operations, and location. With updated capabilities to monitor door opening and closings, dispatch and other wireless monitoring activities, Discrete Wireless provides theft protection and helps reduce insurance premiums (Discrete Wireless Website, 2007, and FleetOwner, 2002). Thom Tech Design has primarily provided GPS/AVL solutions and electronic reporting for tracking of highway maintenance vehicles. Remote data collection devices would retrieve information from trucks for transmittal to databases belonging to clients like Mn/DOT.

Three alternatives were considered for transfer of data from the truck engine computer into the M5 management information system. These include Qualcomm's OmniTracs, PeopleNet's Web-based fleet management interface, and the addition of wireless capabilities to the pre-existing Mn/DOT configuration. Qualcomm's family of mobile computing platforms uses a nationwide satellite link to transfer information between truck drivers and home bases. Vehicle location, operations reports, and text communication can be sent using this system (Parry, 2002 and Qualcomm Website). Like OmniTRACS, FleetHawk uses an onboard transceiver to monitor monitor driving patterns, vehicle location, and operations data (FleetOwner, May 1, 2004). This information is then uploaded to Skytel's database and can be viewed online by the fleet manager (Skytel Website, 2006). PeopleNet also uses two-way communications from the truck and driver to the fleet manager via PeopleNet's database. With this system, there is the possibility of integration with Mn/DOT's databases (PeopleNet Website & FleetOwner, December 1 2006). A comparison of some of these devices is made in Table 3-1 in order to make recommendations based on criteria satisfaction, cost effectiveness and overall feasibility of implementation. Mileage, fuel consumption and idle time data cannot be collected using Skytel's FleetHawk system (Wynn, 2007). As such it will not be considered further. Qualcomm is currently researching compatibility issues in an alliance with Maximus asset solutions and trucking companies.

The Qualcomm and PeopleNet systems are characteristic of the “state of practice.” Fleet management products by these companies are used at Halvor Lines Inc., Target Inc., Schneider National Trucking and Logistics Company, and Atlas Van Lines, among other companies. These, however, almost always require use of the manufacturer’s web-based interfaces. It is highly desirable that the solution to the automated data acquisition problem be compatible with M5. While PeopleNet’s software could be manually uploaded and entered to M5, there are monthly expenditures for system upkeep.

	Dossier Onboard	Discrete Wireless	Thom Tech Design	OmniTracs	PeopleNet
GPS	x	x	x	x	x
AVL	x	x	x	x	x
RPM	x	x			
Hours of Operation	x			x	x
Fuel Consumption	x	x	x	x	x
Mileage	x	x	x	x	x
Air Temperature			x		
Pavement Temperature			x		
Wing Up/Down		x	x		
Material Usage			x		
Speed	x	x	x	x	x
Oil level	x				
Real-time Data Transfer	x	x	x	x	x
Windows XP/Vista	x	x	x	x	x
Report Generation	x	x	x	x	x
Two way messaging					x

Table 3-1 Comparison of Data Acquisition Systems

(Adapted from HHC Auto Solutions, 2006)

From discussions with Mn/DOT personnel, the ThomTech system is no longer a viable option. From Table 3-1, Omni-tracs or PeopleNet remain viable options. It might, however, prove optimal to introduce wireless capabilities to the existing system. Manufacturer-specific software is used in the data collection/monitoring process at Mn/DOT's Duluth locations. While the Qualcomm and PeopleNet systems can be programmed for communication with the onboard computers and databases, ongoing variable maintenance costs make these less than ideal for recommendation for initial wireless tests. It would, thus, be practical to test wireless capabilities in the Duluth location by adding wireless capabilities to the current system of collecting data from the trucks.

Modem Selection

Several modems were considered for use in snowplow operations data acquisition. Summarized in Table 3-2, final comparisons were made between the three modems from two manufacturers: (1) Digi Connect® Wi-SP by Digi International, and (2) XBee Zigbee/802.15.4 RS-232 RF Modem and (3) XBee-PRO Zigbee/802.15.4 RS-232 RF Modem by Maxstream.

Modem	Digi	Maxstream (Development Kit)	
	Digi Connect	XBee	XBee-PRO
Range			
Indoor	Variable	100'	300'
Outdoor/RF line of sight	Variable	300'	1 mile
Data rate			
RF	N/A	250 Kbps	
Interface	≤ 110 Kbps	≤ 115.2 Kbps	
Operating Frequency	2.4 GHz	2.4 GHz	
Channel Capacity	11 channels	16 channels	12 Channels
Power Requirements			
Supply Voltage	9 - 30VDC @ 450mA	2.8 - 3.4 V	
Operating temperature	.-4°F to 149°F	.- 40°F to 190°F	
Size	4.188" x 1.680" x 0.999"	0.960" x 1.087"	0.960" x 1.297"

Price	USD 375	USD 129	USD 339

Table 3-2 Modem specifications

Considering initial unit purchase prices, operating temperature ranges, channel capacities, and range requirements, the Maxstream XBee modem was selected for initial tests. Images of the Maxstream XBee device are located in the Appendix.

Final Modem Test

Figure 3-4 contains process maps for the original data acquisition process and the attempted process, using the modems. These are intended to highlight gaps in the system, in addition to Figure 3-3 above, and thus facilitate the eventual implementation of wireless capabilities. Details of the testing process are included, along with images, in the appendix to this report.

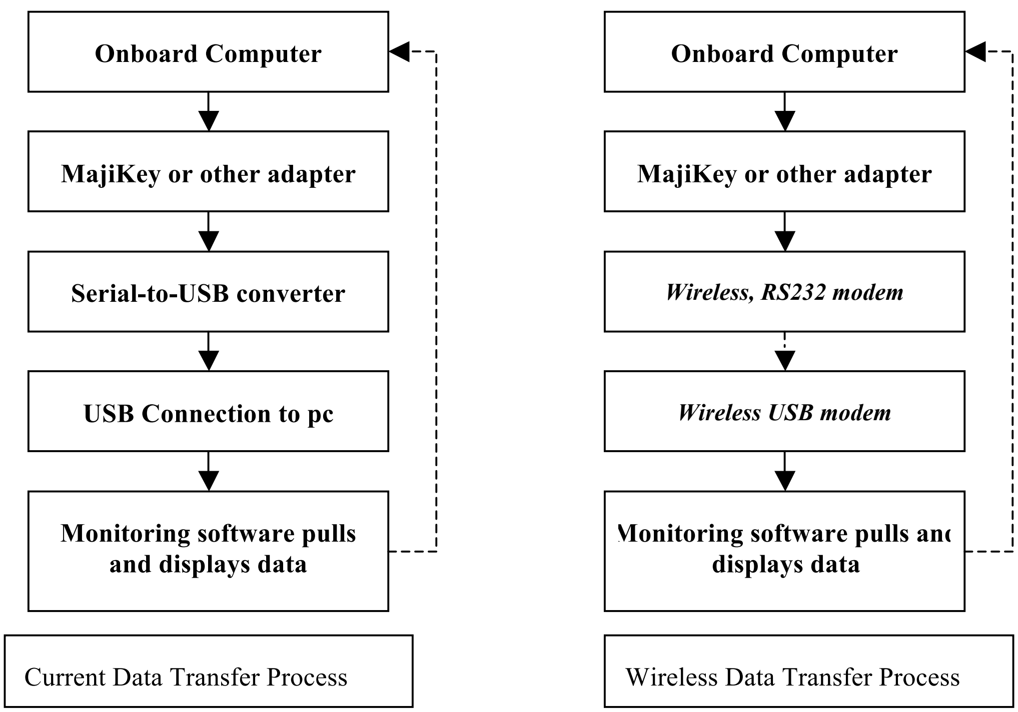

Figure 3-1 Current vs. Attempted data acquisition processes

Mn/DOT currently uses direct wire connections to retrieve data from the snowplow engine computers. Due to manufacturer information plug outlet designs, a MajiKey (device with multiple mates for manufacturer outlets) is used to make the connection from the computer to the truck. A Maxstream modem (transmitter) was connected to the truck via the majikey, with the other modem connected to the computer following the normal wire connection procedure as shown in the appendix.

While the Figure 3-4 shows a system that should function effectively, problems arose during attempts at modem communication with manufacturer specific software. Absence of manufacturer support for wireless data transfer and an aversion to information sharing by firms that have had success in this process, resulted in a decision to conduct further trials after consultation with Electrical and Computer Engineering personnel at the University of Minnesota Duluth. Licensing restrictions prevented the installation of monitoring tools on UMD computers; the single "garage laptop" for which Mn/DOT had obtained a license was not available for tests due to possible downtime considerations. Further tests were conducted on Caterpillar and Cummins engines to rule out truck or manufacturer specific errors, or restrictions.

In a study by Fleetrio Consulting (2005, surveys of Mn/DOT District 1 employees were conducted for identification of intangibles to be considered in the determination and implementation of fleet management solutions. A few of the intangibles considered are listed below:

- **Control of Vehicle:** Some people liked the newer electronic controls and some thought the old hydraulic controls were causing them injuries. On the other hand there were also complaints about the lack of feedback and the lack of instant reactions with the electronic controls.
- **Control of Data:** Only 34% of the people said they would want automated data collection, something that should make their job easier, seems to indicate that the drivers want to feel in control of their data.
- **Uniformity:** When asked if it would be beneficial for all vehicles for performing a particular function to be identical, 78% said yes. There were many reasons given for this, such as ease of maintenance, ease of operation, and less chance of errors. On the other hand many comments were made questioning the practicality of this concept.
- **Safety:** Safety is obviously a major intangible for fleet vehicles. If new vehicles can be shown to be safer than it would seem that replacing vehicles sooner would have a positive economic effect by decreasing accidents and the threat of lawsuits. The questionnaire seems to indicate that the drivers don't feel that newer vehicles are safer. They were just about evenly split when asked if new vehicles had better visibility, and only 40% said they felt safer in new vehicles. A study could be done to look at accident reports and investigate if newer snowplows get in accidents less frequently. If they are found to, these data could be used to assign a safety cost to plows depending on their age.
- **Reliability:** Of the people surveyed, 40% said the age of the vehicle did not matter … many of those people also commented that it was the condition and reliability of the vehicle that ultimately mattered to them. It is easy to see how having a snowplow

breakdown can be costly; the loss of production is difficult to measure and keep track of, but could impact a life-cycle cost greatly.

With many staff members opposed to wireless data collection processes, a detailed explanation of each process was conducted and a Mn/DOT employee was present during all testing stages. Said aversion, however, resurfaced when initial tests of the Maxstream modem led to the need for programming to allow wireless communications. This raised concerns about the feasibility of successful wireless transfer implementation upon project completion.

With proposed plans for fleet pooling with other state government agencies, wireless capabilities would be ideal for data acquisition at Mn/DOT. This would enable remote inspection and diagnosis, while optimizing utilization and reducing fuel and wear expense. In spite of initial employee aversion, the benefits of proposed improvements far outweigh any concerns, though valid, raised against wireless implementation. Adjustments to manufacturer software were avoided due to the threat of possible lawsuits brought by engine manufacturers for "breach" of their codes. This would result in additional expense for Mn/DOT. The acquisition of a license for operation of Cummins Inc. or Caterpillar Inc. software would permit tests, in conjunction with UMD ECE personnel, which would adjust configurations to allow for wireless data transfer.

Task 7: Prepare presentations, reports and articles.

Throughout the preparation and undertaking of this project, presentations have been made in regular meetings with Mn/DOT personnel in Duluth. Additionally, a presentation was made at NATSRL Research Day in 2005.

Quarterly reports have been filed through the Center for Transportation Studies at the University of Minnesota.

Two peer-reviewed conference proceedings articles have been published by the American Society for Engineering Management (Katmale and Wyrick, 2006; Eseonu and Wyrick, 2007). These technical papers were also presented at the ASEM annual meetings.

In addition, one senior design team of mechanical engineering and industrial engineering majors focused on this project (Carlson, Hakala, and Hovde, 2006). It should be noted that this approach to involving undergraduate engineering students has been very successful at exposing them to issues in transportation engineering and in supplementing the work effort of the research team.

4. Alternatives, Recommendations and Conclusions

The preceding chapter presented the results from the research. In order to put these results into action, a decision should be made to determine the course of action to pursue. This final chapter provides a set of decision alternatives, analyzes those alternatives, and proposes recommendations based on this analysis. In addition, conclusions and ideas for future work are provided.

4.1 Alternatives

Several alternatives were considered as solutions to the problems with Mn/DOT's data collection process and issues with data quality. Alternatives will be discussed, here, in four main categories:

1. Increase frequency of hardwire data collection
2. Use external service providers
3. Develop own system
4. Collaboration with engine manufacturers

Option 1: Increase frequency of hardwire data collection.

In order to ensure maximum operation in Zone B of Figure 3-2, optimal preventative maintenance schedules must be determined. This will require an **increase** in **the frequency of hardwire data collection**. Statistical models were utilized in the work carried out by the Road Runners Research Group to determine optimal maintenance schedules. The process of data collection could then be formalized as a policy requiring data collection at every maintenance event or visit to the shop. Mn/DOT currently relies on manufacturer recommendations and personnel experience in determining maintenance frequency.

Pros: The advantages of this course of action include an increase in forecasting and decision making accuracy, increased detection of anomalies in data entries through increased interaction with the system and familiarity with normal trends.

Cons: Increasing the frequency of data collection places greater time requirements on Mn/DOT employees. The need, in some cases, to transport vehicles to garage locations for data collection would increase tire and brake wear among other things.

This option does not require purchase of new equipment. Major alterations to current practices focus on the frequency of data collection and the use of collected data in failure prediction and maintenance scheduling.

Option 2: Use external service providers.

The use of external service providers is a data collection method utilized by companies like Target Inc., Atlas Van Lines and Halvor Trucking Company, to monitor their fleet. This is an effective management practice for these companies because they provide services to locations across state boundaries and, in some cases, across national borders. Qualcomm and Peoplenet provide options for monitoring driver activity in addition to GPS and vehicle operations updates and are the two external service provider firms most widely used by client companies.

Pros: This method of data acquisition would provide real time fleet operations data and allow for more effective management decisions and predictive maintenance practices as advocated by Huff, Mariucci, Uecke and Zabel (2002). Additional benefits of these systems include minimal time requirements of employees and high data quality due to standardization and reduced human intervention

Cons: Recurring expenses in the form of piecewise setup costs ($1200 - $1500 per unit, or about $960,000 for the use of PeopleNet devices for the Mn/DOT fleet), monthly subscription fees ($25 - $35 per unit or about $240,000 per annum for the entire Mn/DOT fleet), maintenance charges, et cetera, make this option less desirable. This is more so in light of budgetary constraints and possible future fluctuations in the allocation of funds. Data collected in this manner is stored on, and accessed via, third party web portals.

Option 3: Develop own system.

This option would allow Mn/DOT to design software that adequately satisfies data collection requirements and would prove useful if fleet pooling comes into effect. Mn/DOT and other state departments plan to begin a seasonal fleet sharing scheme in order to optimize resource utilization.

Pros: Such a system would be designed to Mn/DOT specifications. Mn/DOT proprietary software would be available for research into methods for further improving data acquisition, unlike external manufacturer software on which Mn/DOT has limited testing capabilities without manufacturer permission. In addition, the work undertaken to create such a system would increase employee technical "know-how."

Cons: Systems of this nature are prohibitively expensive to produce, test, and implement. The cost of such a system would outweigh its benefits, especially as the number of data sets to be collected automatically has been reduced considerably – since the end of the Life Cycle Costing projects - through improved data entry practices and the implementation of M5.

Option 4: Collaboration with engine manufacturers

An agreement by engine manufacturers to open wireless access by disabling firewalls or other restrictions triggered by the introduction of wireless modems, would make for a cost effective method of wireless data transfer. This would allow Mn/DOT introduce the Maxstream modems, or similar devices.

Ongoing collaboration between companies like Schneider National, Maximus Inc., and Qualcomm, suggest the viability of such options.

Pros: This option would give Mn/DOT access to manufacturer expertise and reduce challenges with compatibility. The end product would be an excellent data acquisition system that would be easily implemented in other parts of the state. An arrangement of this nature would also incur less expense than in-house creation of a similar system.

Cons: Differences in work ethos could negatively impact collaboration. The tendency to let experts handle work in their area of expertise could reduce knowledge acquisition by Mn/DOT staff.

4.2 Recommendations

The third party service providers, Qualcomm and PeopleNet, have substantial experience in this area and are currently primarily used in commercial companies with fleet that make frequent long haul trips. The capabilities of these systems can be reasonable investments for commercial firms like Target and Atlas Van Lines, but probably not for a governmental agency with tight budget requirements because of the subscription and maintenance charges. However, considering the negative results of the tests on wireless modems and the complexities and time and monetary demands of proprietary software, the better economic viability of this option becomes apparent.

Mn/DOT proprietary software would provide organization-specific solutions and make for possibly easier updates and adaptation as demands change. However, the design and implementation of such a system would require considerable time commitments from Mn/DOT employees while running the risk of producing sub-optimal systems when compared to products of companies like PeopleNet, which are solely in the fleet management software development business. This option is, thus, considered to be sub-optimal as a final solution to the data acquisition needs discussed in this project.

It is, thus, recommended that a move be made to predictive maintenance practices in the long run. That this long term approach aim to improve data quality by (1) training personnel and (2) working with Maximus Asset solutions to build “checks” into data collection systems that limit the occurrence of bad data and raise flags when questionable data is logged.

At present, the frequency of data collection via the hardwired connections should be increased in order to ensure operation in the optimal Zone B of Figure 3-2. Where wireless data collection, or automation of the process becomes a priority, it is recommended that option 4; collaboration with engine manufacturers; be explored. Should this prove unsuccessful, the use of data collection systems by PeopleNet or Qualcomm should be considered. As was discussed earlier, ongoing tests by Scheider National, Maximus and Qualcomm aims to facilitate upload of data from third part web portals to client databases – M5 specifically.

Other possibilities include the use of the modems tested here for chemical and sand data acquisition. Current systems collect data with the aim to aid the snowplow operator in making decisions and controlling dispensation. None of the data are currently stored and predictions are usually inaccurate. Historical data would be useful in achieving better accuracy in this area.

4.3 Conclusions

This research project has investigated the automatic data acquisition process for transferring engine information from a truck into the M5 management information system. From discussions with Mn/DOT personnel and review of previous reports, data for automatic acquisition include fuel consumption and mileage/odometer readings, fault codes, and hours of operation.

The evolution in capabilities of automated vehicle data acquisition was satisfied through a review of literature and discussions with university and industry experts and transportation researchers. As a result, this section was classified into two main categories. They are state of the art and state of the practice. State of the art refers to recent innovations and ongoing research in a field/on a subject (automated data acquisition in this case). Recent innovations in this field include a move toward intelligent vehicles with data detection, collection, processing, and feedback execution abilities. With fleet management in general, this increasingly implies safe vehicles that monitor interaction between long haul drivers and road conditions or other road users and can take actions either to alert the driver of external conditions requiring his or her attention, or to prevent the driver from making errors.

As M5 utilizes Extensible Markup Language (XML), which is primarily aimed at information sharing, there is the possibility of incorporating wireless capabilities. Work is being carried out in industry to allow for communication between M5 and Qualcomm systems. The inability of a number of databases in use at Mn/DOT, including M5, to communicate with each other is, in part responsible for the acceptance of bad data. The need to incorporate “accuracy checks” into the databases was discussed.

Process maps depicting current data collection process and desired wireless transfer process to analyze the current system and identify differences from desired process. The gaps in overall system performance and potential improvements lie in the transfer of information from the truck engine into the M5 system.

After evaluation of alternatives including the use of third party systems and the incorporation of wireless capabilities into the current system, tests were conducted using the chosen alternative: Maxstream modems. Proprietary restrictions on the engine computers prevented wireless data transfer. This led to the analysis of various fleet management strategies. The recommended action at this time is to increase the frequency of the current practice of hard-wired data collection as necessary. If real-time data acquisition is deemed to be absolutely necessary, then one of the third party service providers, such as Qualcomm or PeopleNet, should be considered.

This project has resulted in two peer-reviewed conference proceedings articles to date. It also provided one senior design team in mechanical and industrial engineering at the University of Minnesota Duluth to work on a real-world scenario in transportation engineering.

4.4 Future Research

Several recommendations for further research and investigation can be made as a result of this project. The four top suggestions are provided below.

1. In light of increasing emission regulations, research into fuel conservation, the eventual use of alternative fuels, and supporting technology, is required.

2. In order to effectively determine optimal fleet life cycles and engage in effective maintenance practices, research is needed into methods of determining minimum acceptable quality levels (completeness, accuracy, relevance, timeliness, et cetera) for recorded data. Steps should also be taken to make required improvements.

3. The cost of tire replacement is prohibitively high. Breakdowns resulting from unnoticed tire failures can prove costly (downtime productivity losses, towing, and subsequent repair charges). Research is, thus, needed into means of predicting or facilitating monitoring of tire wear. Michellin's eTire II chip could serve as a solution to this problem.

4. Where real-time, wireless transfer is not viable, methods of determining optimal data collection and maintenance points are needed. The current system relies on manufacturer recommendations and previous experience to set targets for maintenance intervals (Baldwin and Cameron, 2007)

Glossary

DOT	Department of Transportation
ECE	Electrical and Computer Engineering
GPS	Global Positioning System
GRA	Graduate Research Assistant
MAPS	Minnesota Accounting Procurement Systems
MDOT	Michigan Department of Transportation
Mn/DOT	Minnesota Department of Transportation
NATSRL	National Advanced Transportation Systems Research Laboratory
RCA	Resource Consumption and Allocation database
RF	Radio Frequency
UMD	University of Minnesota Duluth
WMS	Work Maintenance System Database
WEX	Wright Express System
XML	Extensible Markup Language

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Appendix

Prototype/Modem Testing

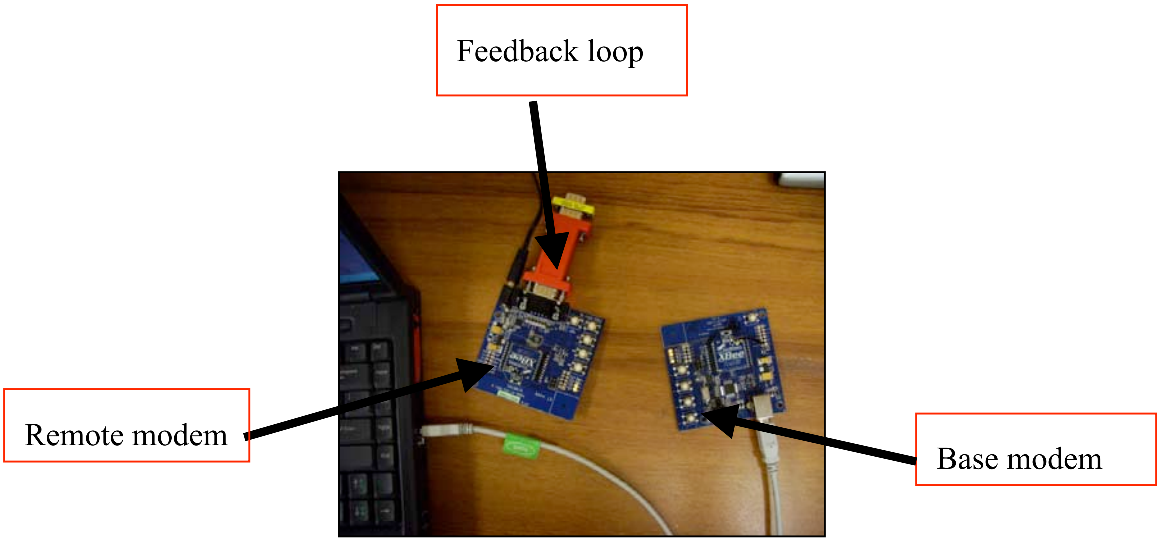

Figure A-1 Modem circuit boards

Figure A-2 Connection between remote modem and truck using majikey

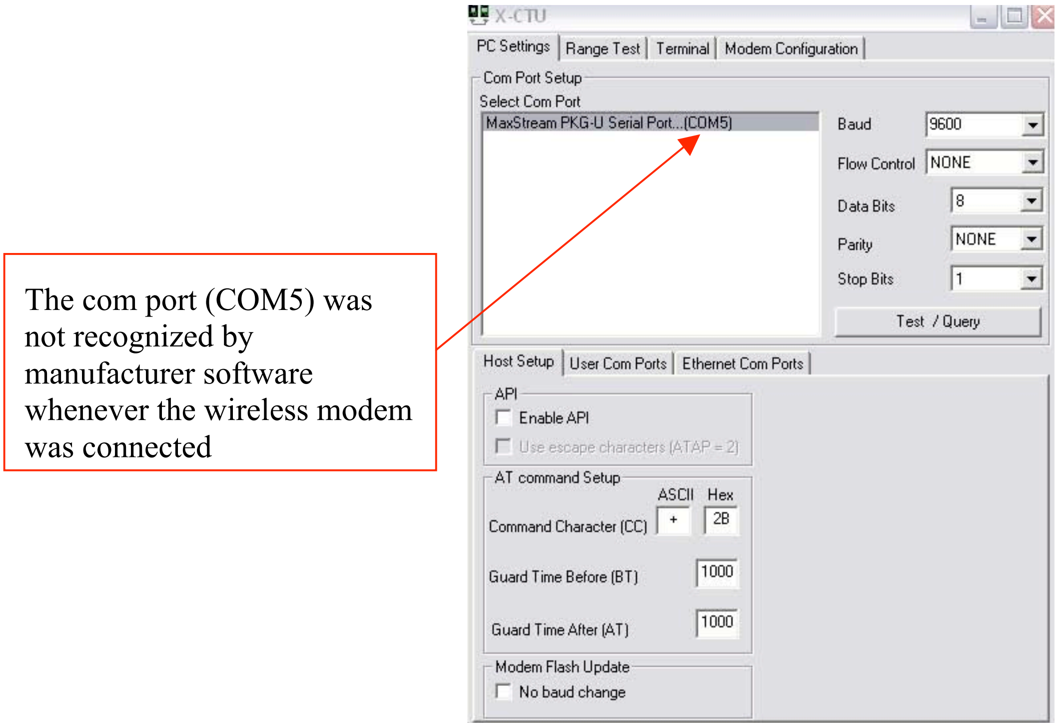

Figure A-3 Maxstream X-CTU software settings for modem test

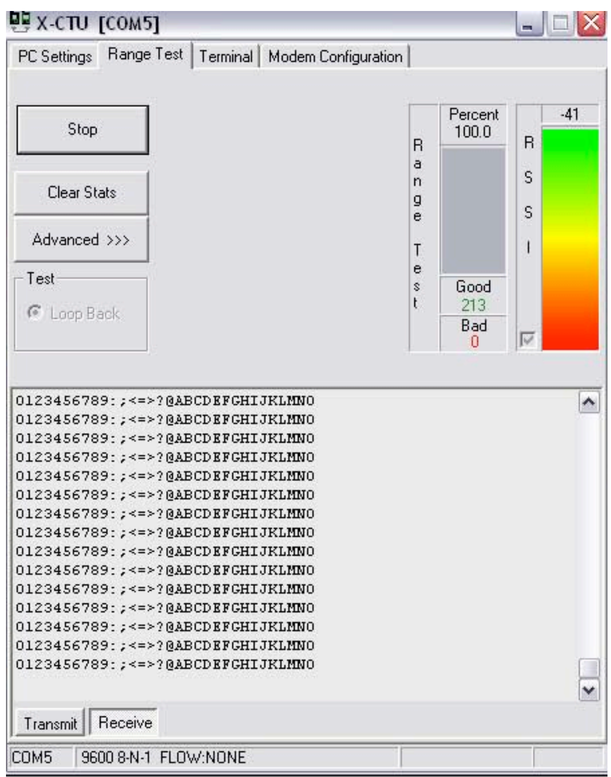

Figure A-4 Maxstream X-CTU software feedback from remote modem

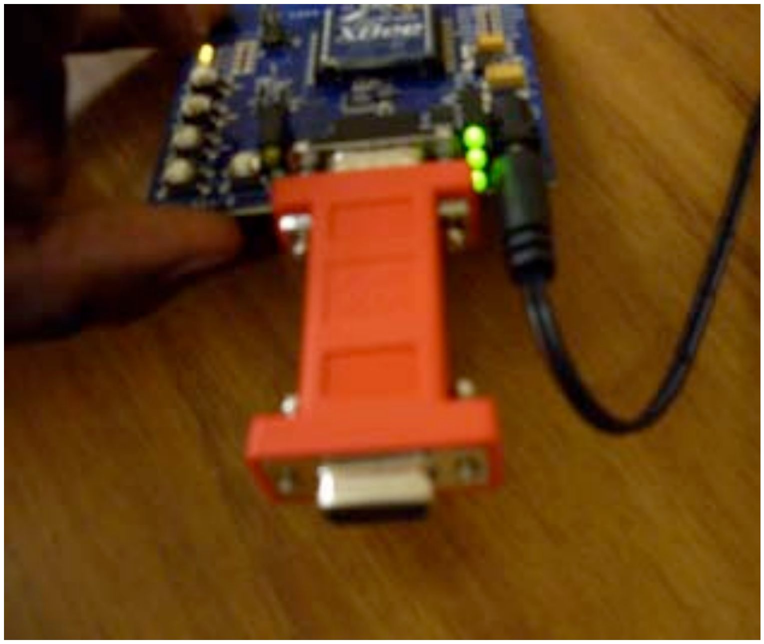

Figure A-5 Remote Modem during test

To be connected to vehicle. Green lights signify connection with base modem

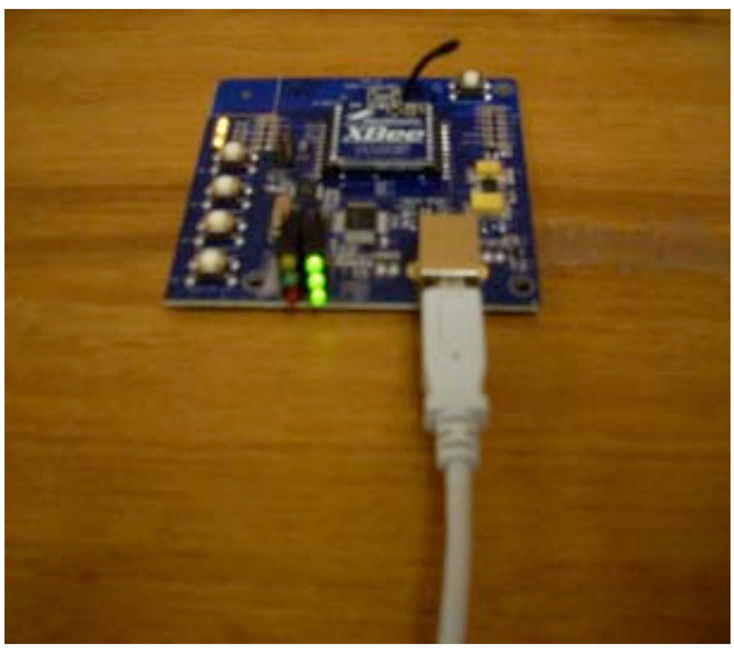

Figure A-6 Base Modem during test

Connected to laptop. Flashing lights signify communication with remote modem