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SD Department of Transportation
Office of Research

Verification of Radar Vehicle Detection Equipment

Study SD98-15
Final Report

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Rocky Hook ....Data Inventory
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16. Abstract

Currently, inductive loops are used to count traffic at the 52 permanent sites located in South Dakota. Because they are located within the pavement, the loops are susceptible to being destroyed during maintenance projects. When they are destroyed, it is necessary to close traffic in that lane, cut a loop into the pavement, and fill the void left in the concrete. This study explored the potential implementation of a non-intrusive sensor, the RTMS. The RTMS is installed adjacent to the roadway so it is not at risk of being destroyed when maintenance is performed.

In this study, the RTMS was evaluated for both its cost effectiveness and reliability. From manual counts, it was found that the RTMS tended to count 3 percent low. It was more accurate than road tubes, which were also used to compare to the manual counts. According to the Office of Data Inventory, the accuracy of the inductive loops is dependent on the counters that they are run through.

The initial cost of the RTMS tends to be higher than that of inductive loops. But, if the pavement is in poor condition, it is probable that the loops will be in need of replacement before the end of their expected lifetime. This will cause the lifetime cost of the inductive loops to be more than that of the RTMS. In the case of speed surveys, the inductive loops are far less expensive to implement than the RTMS.

Due to its reliability, it was determined that the RTMS should be implemented if it is cost effective. In other words, if the lifetime cost of implementing the RTMS is less than or comparable to that of the inductive loops, it should be implemented. Otherwise, the inductive loops should be reinstalled at that location. Other potential implementations of the RTMS, such as a mobile counting station, were explored as well.

Due to problems the Minnesota DOT found with the predecessor to the RTMS used in this study, it is recommended that further testing be done on the RTMS to verify that it counts traffic accurately during snow, rain, and freezing rain.

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Chapter 1

Executive Summary

The South Dakota Department of Transportation performs traffic counts at 52 permanent sites throughout the state. Currently, inductive loops imbedded in the pavement are being used to perform these counts. The problem is that the loops are prone to being destroyed when maintenance is performed on the roadways. Therefore, it was decided that other options for the traffic counting needed to be explored.

A non-intrusive system was chosen to be tested for traffic counting. The Remote Traffic Microwave Sensor (RTMS) manufactured by Electronic Integrated Systems Inc. (EIS) was selected because it is placed above the roadway and because of its performance in similar applications. The RTMS was tested for its ability to accurately count traffic, and it was compared to the inductive loops for its cost effectiveness.

Next, a site needed to be selected for testing the RTMS sensor. A portion of Interstate 229 in Sioux Falls was selected because its inductive loops were not operational. In addition, this site would show the abilities of the Microwave sensor in high traffic situations.

The sensor was mounted to a pole overlooking the interstate, and the setup was complete in a matter of hours. Once connected to a power source and traffic counters, the sensor was calibrated. After the operation had been verified, it was decided that counting would begin the next day.

The counting ability of the RTMS sensor was verified by performing manual counts and road tube counts simultaneously with the RTMS counts. The counting took place over the course of two days, and there were a total of twenty-one hours in which counts were taken. As a result of the testing, it was found that the RTMS counted 43,701 vehicles and the manual counts found

45,062 vehicles. These results were used to calculate that the error for the RTMS data was 3 percent low, assuming that the manual counts were correct.

Because the inductive loops and the RTMS sensor can both be run through the same type of traffic counters, the systems are compatible. Therefore, the SDDOT can use the RTMS sensor for certain traffic counting sites while using inductive loops at others.

When inductive loops, which are currently in the pavement, need to be replaced, a decision needs to be made whether to install inductive loops or the non-intrusive sensor. Because of the nature of the various systems, it is recommended that the inductive loops only be installed when they are less expensive than the RTMS. In addition, the roadway in which they will be installed must not be in need of any maintenance requiring sawing or removal of the pavement. Finally, inductive loops must be implemented if speed surveys are required at the traffic counting site. In all other cases, the RTMS sensor should be implemented.

Another potential use for the Microwave sensor is for a mobile counting station. The RTMS would be ideal for this type of application because it is mobile and easy to set up. In addition, if a certain site is used more than once, the calibration can be saved and reinitialized when the sensor is returned to the site.

Chapter 2

Problem Description

The Office of Data Inventory is responsible for monitoring traffic throughout the state. Permanent equipment has been installed at 52 sites on various highways to count and report the volume of traffic flow. It is important for the South Dakota Department of Transportation to maintain the traffic flow counts because the data that is collected is used by many offices within the SDDOT. The traffic data is used to help make decisions for accident analysis, highway geometric design, allocation of highway funds, pavement design, and pavement management.

The permanent equipment currently used by Data Inventory is in the form of inductive loops that are embedded in the roadway. As the inductive loops at these sites deteriorate, and when the need for new sites arise, new equipment must be installed into the pavement. In order for this installation to occur, it is necessary to close traffic in a particular lane. Once the traffic has been diverted, highway workers must make saw cuts in the pavement and place the loops into the cuts. Next, the wiring for the inductive loops needs to be run from the loops to the edge of the road in order to connect the loops to a traffic counter. Finally, the voids in the pavement, which were left as a result of the saw cuts, need to be filled. This process needs to be repeated for the other lanes requiring new inductive loops. It takes approximately four hours to install a loop and allow for the sealant to set up.

Currently, there is equipment available that does not damage the pavement, would not cause driver delays from lane closures, and does not risk the safety of staff by exposing them to traffic during in-pavement installations. This new equipment can be collectively referred to as non-intrusive vehicle detection equipment. Non-intrusive systems are placed off of the roadway and do not require in-pavement installation. The various forms of systems can either be mounted above or to the side of the road on an overpass, a light pole, or another similar structure.

The non-intrusive system which was studied is a Remote Traffic Microwave Sensor (RTMS) produced by Electronic Integrated Systems, Inc. (EIS). The RTMS was chosen for this study due to the fact that it has been shown to be reliable for similar applications. According to the literature provided by EIS, the RTMS sensor, when correctly mounted and configured, will produce traffic counts that are up to 97 percent accurate. In addition, EIS claims that their RTMS sensor is designed to have a mean time between failures of 90,000 hours (10 years). This is comparable to the life expectancy of undisturbed inductive loops.

This research project will evaluate the RTMS on cost, ease of installation and use, and accuracy. In addition, the RTMS and inductive loops will be compared to one another on their cost effectiveness and accuracy.

Chapter 3

Objectives

For the Verification of Radar Vehicle Detection Equipment project, there were two main objectives which needed to be accomplished. Those two objectives were:

- To compare the traffic counts found by a Microwave sensor over distinctive lanes of traffic to those counts produced by inductive loops and manual counting

- To determine the cost effectiveness of the Microwave sensor compared to that of the inductive loops for both rural and urban situations

The first objective was an attempt to check the quality of the data found by the non-intrusive system. The purpose was to determine how close the findings of the RTMS sensor were compared to the actual traffic flows. By performing manual counts, as well as the counts from the Microwave sensor and inductive loops, one could verify exactly how accurate both traffic counting systems are at that particular site. A percent error will be calculated for the counts tabulated by both the non-intrusive sensor and by the inductive loops.

Secondly, the cost effectiveness needed to be found. Determining the cost effectiveness is meant to show the feasibility of installing radar vehicle detection equipment in various situations. The costs of installation and maintenance, as well as life expectancy, for the two systems will be found. This comparison helped to evaluate the inductive loops and non-intrusive sensor purely on an economic basis.

Chapter 4

Task Description

Task 1 *Meet with the project's technical panel to review the project scope and work plan.*

The first task to be completed was to meet with the project's technical panel to review the project scope and work plan. The technical panel, consisting of Jon Becker, Rocky Hook, and Dan Strand, met in May 1998 along with David Huft and Nathan Weber to discuss the project. During this meeting, the objectives of the project were determined as well as the location and duration of the study. As a result of this meeting, the RTMS was ordered from EIS.

Task 2 *Conduct a literature search to obtain knowledge about the installation, ability, and use of Microwave sensors.*

Next, it was necessary to conduct a literature search to obtain knowledge about the installation, ability, and uses of the RTMS. This search included other users of the RTMS sensors, Electronic Integrated Systems Inc. (EIS), and the Internet. In addition, the Internet was used to gather information on how the inductive loops compared to the RTMS on their cost, ability, and ease of use.

According to EIS, the RTMS has been successfully used for many applications. Some of these applications are traffic counting, speed measurement, off-ramp metering and actuation, and incident detection. Traffic counting and speed measurement applications are the two that would be most useful to South Dakota.

While conducting the literature search, it was discovered that the Minnesota Department of Transportation had conducted tests on an RTMS unit. The trials were done with a predecessor to the RTMS sensor used in this study. The only problems the Minnesota study found with the RTMS was that it did not perform to their standards during periods of rain and freezing rain. This was due to the fact that water was entering the housing of the sensor during that period of time. The RTMS was given the highest possible scores for its performance during all other weather and traffic conditions.

The housing has been totally redesigned for the RTMS unit used in this study, so it is believed that those problems will not occur for the new sensor. Despite this, it is recommended that further research be done to verify the operation of the RTMS during periods of rain, freezing rain, and/or snow since these conditions were not present while the testing was being performed for the SD98-15 study.

Task 3 *Participate in manufacturer's training on use and installation of non-intrusive sensor.*

The third task for this project was to participate in manufacturer's training on use and installation of the non-intrusive sensor. For first time buyers of their Microwave sensor, EIS requires that a representative from the company come to the installation location to give on-site training. The purpose of the training is to show how to properly install and use the sensor. On August 3, 1998, the representative from EIS traveled to Pierre to provide training for the RTMS sensor. The training included an in-office presentation that provided information on the software and various features of the RTMS unit. Also, a portion of the training involved the field setup of the RTMS sensor. During that field setup, the RTMS unit was mounted to a pole overlooking the Truck Bypass in Pierre, and several individuals from the DOT were given the opportunity to calibrate the sensor via the software provided by the manufacturer.

Task 4 *Get recommendations for installation of Microwave sensor from EIS representative.*

In addition to the manufacturer's training, recommendations for the installation of the Microwave Doppler systems needed to be obtained from an EIS representative. The company was called to schedule a date for the manufacturer's training, and at that time, a representative was asked to recommend several heights and distances from the road for installation of the sensor. This individual was given the specifics of the test section in order that he could give a proper recommendation. In addition, the field representative, who was in Pierre for the training, provided suggestions on the placement of the sensor. The general consensus from the EIS representatives was that the RTMS sensor should be mounted at a height of at least 17 feet. In addition, they said that the RTMS should be a lateral distance from the roadway of at least 17 feet when it is being used for traffic counting. They both stated that the best case scenario for sites with four or more lanes is that the mounting height and lateral distance from the road be equal. This was to provide coverage of all lanes of traffic without the occurrence of "shadowing", the blocking of a smaller vehicle by a high profile vehicle.

Task 5 *Determine the exact height and distance from the road where the sensor will be placed.*

Now that recommendations had been given, it was necessary finalize the choice of a test site so that the exact placement of the sensor can be determined. The selection of a site was important because the correct location could accurately show the abilities of the RTMS sensor in a practical application, while the wrong site could cause some questions as to the validity of the findings.

The site initially chosen was in Rapid City in a section of town known as "The Gap." This location was selected because there are seven lanes of traffic there. In addition, this location in Rapid City was considered ideal because of the extremely high volume of traffic. It was believed that if the RTMS sensor could accurately count traffic in such high traffic conditions, the sensor could easily work for smaller, less traveled roads.

There were many concerns about the Rapid City site, as well. One problem was that there were not any poles on which to mount the sensor in the vicinity of the inductive loops. Another reason the site was changed to Sioux Falls was because the inductive loops in Rapid City were operational while the loops in Sioux Falls were not. The Office of Data Inventory decided that they wanted data collected at the Sioux Falls site as soon as possible. Therefore, it was decided that the non-intrusive sensor would be tested in Sioux Falls, and once the test period had been completed, the RTMS unit would remain operational to maintain the traffic counts at that location.

For the reasons listed earlier, the site for the testing of the RTMS sensor was in Sioux Falls. The location of the sensor was on Interstate 229 between the Minnesota Avenue and the Western Avenue exits. The RTMS unit is located on the south side of the interstate.

There are many reasons why the site in Sioux Falls was a good location. At that site, there is a relatively high volume of traffic. In addition, there were no operational loops present so it is an excellent site for a permanent installation. Furthermore, power and phone lines were already available at that site, so there was very little effort required to prepare the site for installation.

One problem existed with the site on Interstate 229. There was not a structure on which to mount the RTMS. A speed limit sign was in the approximate location of where the loops had been, and it was located 21 feet 8 inches from the closest lane of traffic. It was decided that a pole would be extended upwards from the sign to reach a height of 17 to 20 feet. Once the pole was in place, the exact height could be determined.

Task 6 *Install the non-intrusive sensor*

Once the exact location was determined, it was necessary to set up the RTMS sensor and to prepare it for use. On August 17, 1998, the RTMS unit was installed and made operational.

When the group performing the testing arrived at the site, Department of Transportation workers were in the process of mounting a timber to which the RTMS unit would be attached. This timber was attached to a speed limit sign, and it extended to a height of 17 feet 8 inches above the roadway.

In order to mount the RTMS sensor to the pole, a bucket truck was needed. First, a mounting bracket with a ball joint, supplied by EIS, was attached to the timber via metal pipe clamps. The RTMS unit attached to the ball joint on the bracket and was secured with a pin. Then the unit was moved via the ball joint until it pointed at the center of the four lanes. Finally, the joint was locked in place with a bolt, and the RTMS cable was attached to the sensor.

The RTMS sensor was mounted to the timber at a height of 17 feet. Once again, the location of the Microwave sensor was exactly 21 feet 8 inches from the beginning of the first lane. It would have been preferred to have the sensor mounted at a height of about 20 feet to avoid shadowing, but the pole did not allow for the sensor to be mounted that high.

Once the sensor was mounted to the pole, it was necessary to calibrate the detection zones of the RTMS sensor. The calibration was completed using the software supplied by EIS and a laptop computer.

The detection zones were set on the sensor and then checked against where the vehicles were showing on the computer screen. Then the detection zones were adjusted. For example, if a car was travelling in Lane 1 and the car was not shown to fall in the Lane 1 detection zone, the detection zone would be moved so the car would fall in the correct zone. This process was repeated for all four lanes.

Once all the detection zones were set, the calibration was checked via a visual inspection. The first two lanes were checked by having one person stating that a car was approaching and which lane it was in. Another individual verified, using the laptop, that a vehicle travelling in Lane 1 or Lane 2 was shown to fall within the particular detection zone on the RTMS. Once enough vehicles had passed to satisfy the researchers that the calibration of the first two lanes was proper, the third and fourth lanes were checked in the same manner.

Overall, the installation of the RTMS sensor was installed quickly and easily. The installation and calibration of the sensor took approximately two hours. The installation could be done much more quickly once those taking part in the setup have more experience. In addition, the sensor was very easy to calibrate. The individual who set up the detection zones had only briefly practiced the calibration process during the training session. He had no problems with the calibration and that portion of the installation took only 30 minutes. The visual check did require some additional time.

While the RTMS unit was being connected and calibrated, several workers were setting up the road tubes for the other portion of this study. Once both systems were set up, they were connected to traffic counters. The traffic counter and the power source for the Microwave sensor was locked into a box at the site, and the traffic counters for the road tubes were locked to the guardrails along the road. At that point, the counters were set to begin collecting data, and the installation process was complete.

Test Section Setup

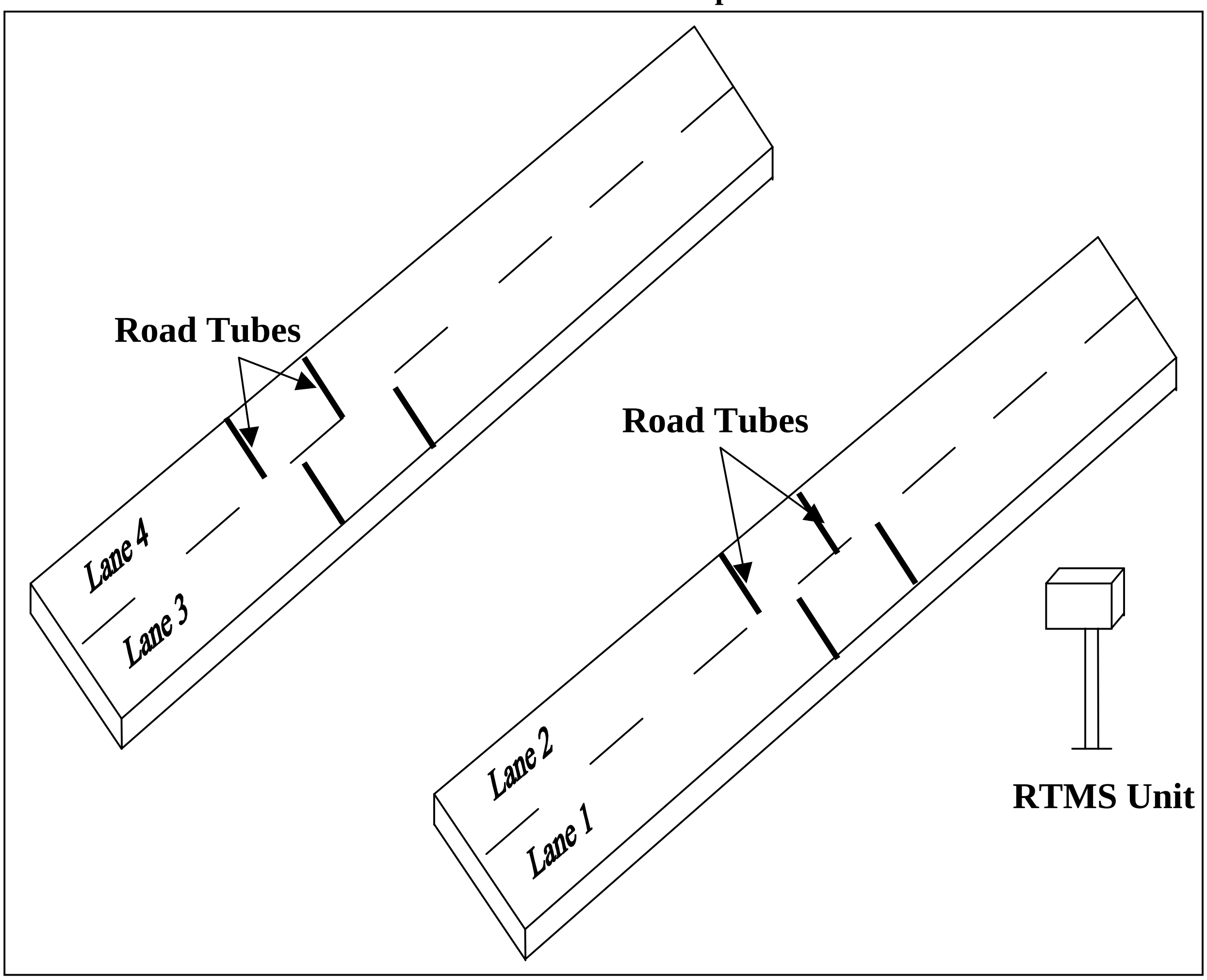

Figure 1

Task 7 *Perform manual traffic counts and compare the data to that of inductive loops and Microwave sensor.*

The testing period of the RTMS sensor took place on August 18 and 19, 1998. Manual counts only took place for twenty-one hours over those two days, but the road tube counts and RTMS counts were being recorded continuously over that period of time. It was important that the data be collected during the overnight hours, as well, so that the operation of the RTMS unit could be verified for a variety of lighting conditions.

Because the Office of Data Inventory stores count data by directional flow rather than by lane flow, the data in this report will be presented in that manner. This means that since the test area is a four lane road, the data for the driving lane and passing lane for a particular direction will be added together to obtain the total number of vehicles for that direction.

On Tuesday, August 18, 1998, the workers performing the manual counts arrived at the test site at approximately 6:30 a.m. At that time, they checked the road tubes, the RTMS units, and the counters for each of the systems to verify that all the equipment was working properly. Once the workers were satisfied with the operation of the systems, the manual counting began. The counts started at 7:00 a.m. and were taken continuously until 6:00 p.m. that evening.

The second day of testing began again at 6:30 a.m. Once again, the systems were all checked to verify that they were working properly. The Lane 4 road tube appeared to be working properly even though, as showed earlier, it was not. In addition, the clocks on the counters were off by up to 15 seconds, but that should not have caused a significant error. Fifteen seconds is only .417 percent of an hour, and one could assume that the average error for the counts that this timing difference would cause would be .417 percent.

The manual counts started at 7:00 a.m. and continued until 5:00 p.m. Data was collected for all three systems during this period of time. Once again, when the counting had concluded for the day, the hourly counts were summed for each direction rather than for each lane.

Testing, Day 1

Northbound Lanes

Below in Table 1 is the data collected for the northbound lanes on August 18, 1998. This table shows the hourly totals for each of the RTMS counts, manual counts, and the road tube counts. Additionally, the daily totals for each method of counting can be seen at the bottom of the table. The total number of vehicles counted for the Northbound lanes on this day were 10737 vehicles, 11024 vehicles, and 11163 vehicles for the RTMS counts, manual counts, and road tube counts respectively.

Next, the data was graphed so that a visual representation of the data could be used. Figure 2 is a graph of the number of vehicles per hour for the northbound lanes.

From the graph, one can see that the RTMS counts tend to be slightly less than those obtained by manual counts or by road tube counts. Additionally, the road tube counts tend to be greater than or equal to the manual counts. This observation goes along with the fact that the total number of vehicles found by the RTMS counts is less than that of the manual counts, and the total number of vehicles found by manual counts is less than that of the road tube counts.

If a person would assume that the manual counts are accurate, then the percent error calculations could be found for the RTMS counts and the road tube counts. These percent errors were found to be 2.6 percent low for the RTMS unit and 1.26 percent high for the road tubes.

Northbound: Day 1

Time	RTMS Counts	Manual Counts	Road Tube Counts
7:00	1075	1147	1153
8:00	757	761	785
9:00	593	599	615
10:00	640	643	648
11:00	856	842	868
12:00	923	939	950
13:00	926	947	965
14:00	949	974	997
15:00	1074	1122	1116
16:00	1344	1386	1394
17:00	1600	1664	1672
Total	10737	11024	11163

Table 1

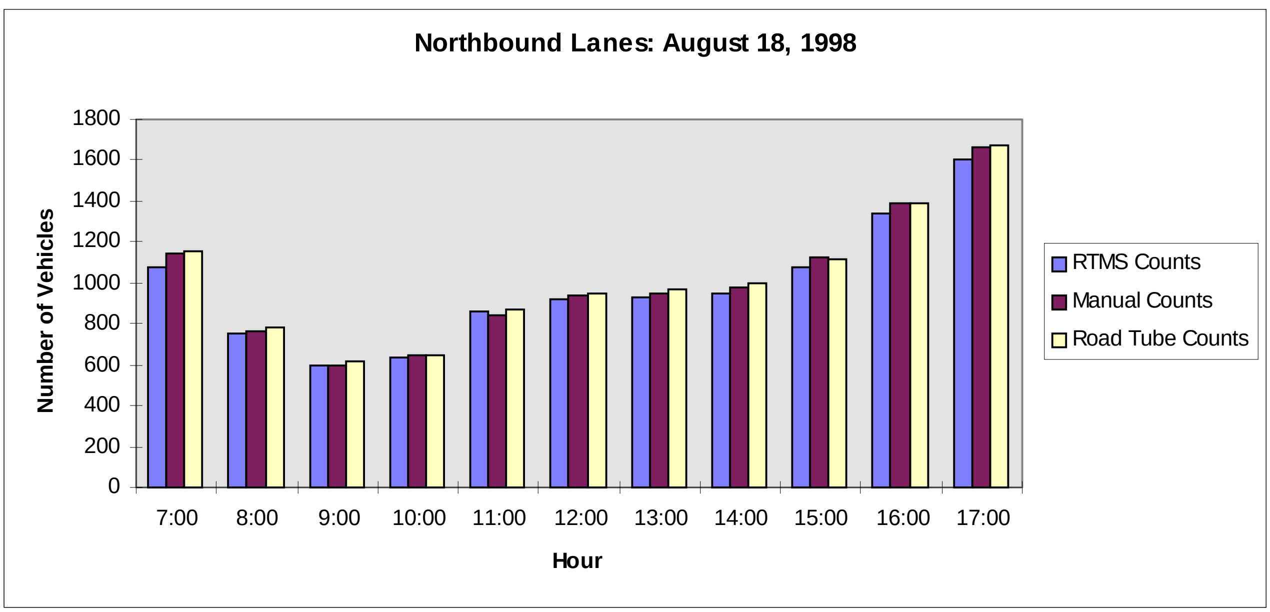

Figure 2

Southbound Lanes

The counts for the southbound lanes for August 18, 1998 are formatted in the same manner as those for the northbound lanes. Once again, the totals for both southbound lanes were added together to obtain the directional totals. Table 2 shows the data for the southbound lanes for August 18, 1998, and Figure 3 shows the graph of this data.

While looking at the data in Table 2, one may notice that the Road Tube data for the 7:00 and 8:00 hours is dissimilar from the other two sets of counts. The data seems to get more reasonable for the 9:00 through 14:00 hours, but it returns to being different from the other two sets of data at the 15:00 hour. This trend remains until the end of the manual counts for the day. These discrepancies can also be seen graphically on the following page in Figure 3.

Like the northbound lanes, the counts for the southbound direction showed similar totals for the RTMS data and the manual data. Despite this, it was found that the road tube counts would sometimes vary drastically from the other two counts. This can be exemplified by stating that the daily totals summed up to be 12878 for the RTMS counts, 13087 for the manual counts, and only 11649 for the road tube counts.

The percent errors were once again calculated for the RTMS data and the road tube data. The values for the percent errors were 1.6 percent low for the RTMS data and 11 percent low for the road tube data. Knowing that the manual data was correct, it was deduced that there were some errors with the road tubes.

While reviewing the data for the southbound lanes, it was found that the road tubes for Lane 4 (Southbound driving lane) were not working properly. To show the problems with the data for the road tube counts, the hourly totals were graphed for Lane 4. That graph can be seen on the next page in Figure 4. While looking at the graph, please note that there are several hours where the road tube counts vary greatly from both the RTMS counts and the manual counts.

While reviewing the data for the rest of the experiment, it was found that the problems with the road tube counts in Lane 4 continued for the duration of the trial.

Southbound: Day 1

Time	RTMS Counts	Manual Counts	Road Tube Counts
7:00	1371	1419	1274
8:00	1095	1086	789
9:00	797	797	806
10:00	878	869	872
11:00	986	995	1021
12:00	1174	1197	1194
13:00	1147	1164	1131
14:00	995	1002	1021
15:00	1147	1177	871
16:00	1519	1580	1127
17:00	1769	1801	1543
Total	12878	13087	11649

Table 2

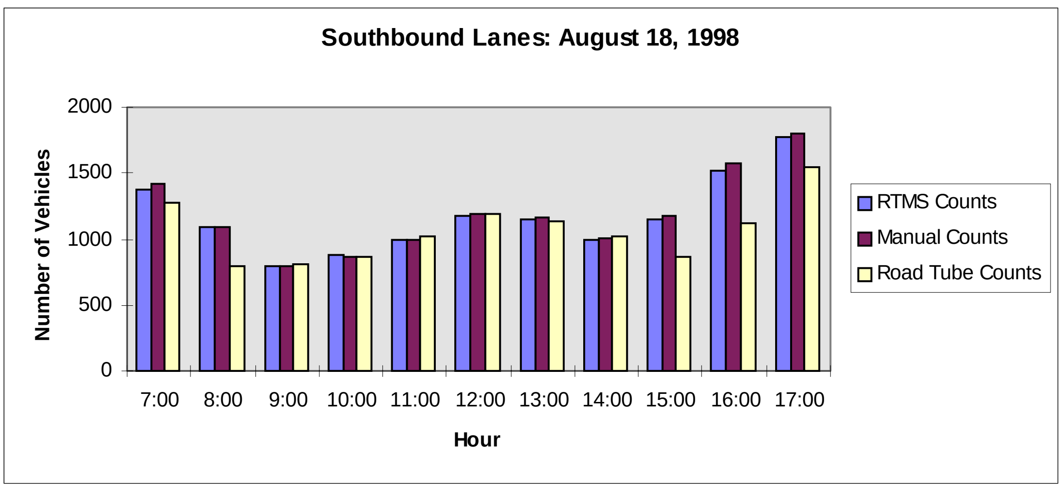

Figure 3

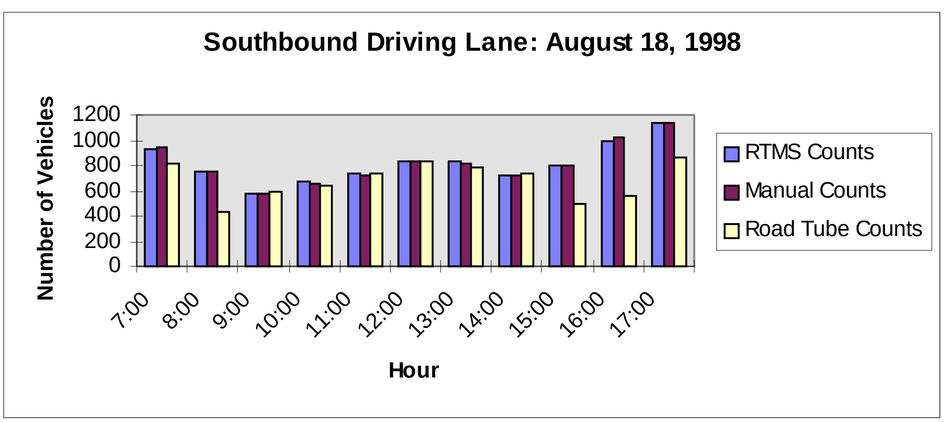

Figure 4

Testing, Day 2

Northbound Lanes

The second day of counting brought about similar results to the first day. The data for the northbound lanes was accurate for both the RTMS counts and the road tube counts. Overall, there were 9370 vehicles for the RTMS counts, 9673 vehicles for the manual counts, and 9725 vehicles for the road tube counts. The hourly counts can be found on the next page in both Table 3 and Figure 5.

The counts produced by the various systems were used to calculate the percent errors of the RTMS and road tube data. The count data produced a percent error of 3.1 percent low for the RTMS data and .53 percent high for the road tube data. Both of the systems produced very reasonable errors.

Northbound: Day 2

Time	RTMS Counts	Manual Counts	Road Tube Counts
7:00	1188	1242	1247
8:00	791	797	804
9:00	604	592	614
10:00	699	696	717
11:00	812	828	836
12:00	944	999	995
13:00	953	978	984
14:00	980	1009	1016
15:00	1119	1179	1169
16:00	1280	1353	1343
Total	9370	9673	9725

Table 3

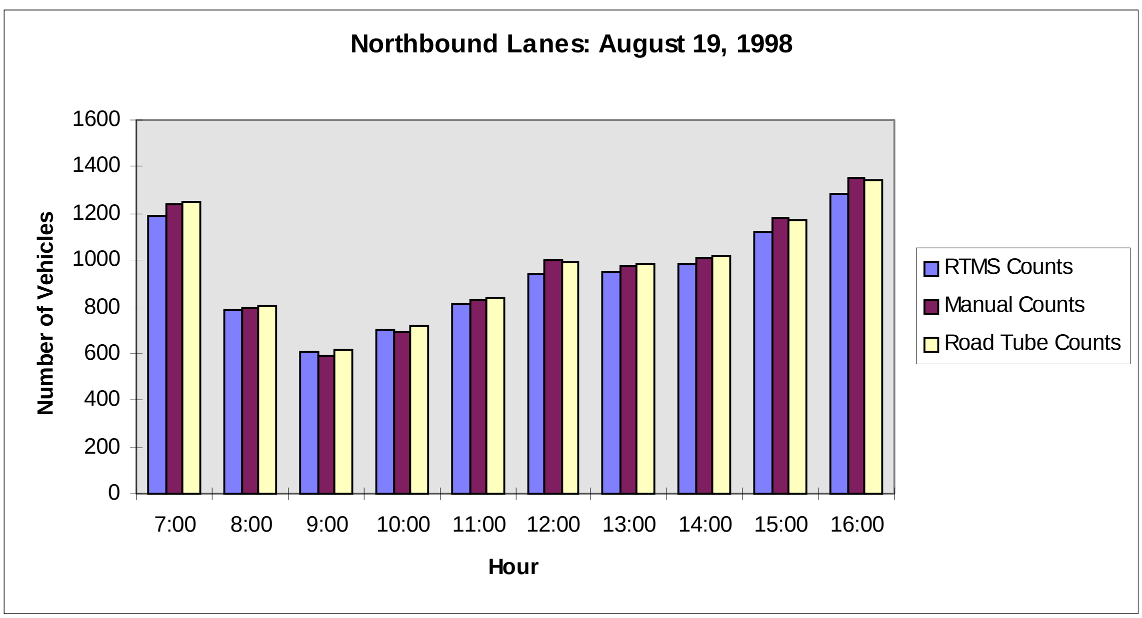

Figure 5

Southbound Lanes

The southbound lanes produced similar results to the first day, as well. The counts produced data of 10716, 11278, and 5405 vehicles respectively for the RTMS counts, manual counts, and road tube counts. It is obvious that the counts produced by the road tubes vary significantly from those produced by either the manual counts or the RTMS counts. The percent errors calculated were 5 percent low for the RTMS data and 52 percent low for the road tubes. The count data can be seen on the following page in Table 4 and Figure 6.

The origin of the errors for the Road Tubes in Lane 4 is unknown, but the errors seem to have gotten larger since Day 1. The data for the northbound lanes appears to be very accurate, so it would be safe to assume that the errors were isolated to Lane 4.

Total Counts

Once the manual counts had been completed, the totals for both days were summed to produce the overall results. First, the total counts for each direction were tabulated. The data for the northbound direction produced values of 20107 for the RTMS counts, 20697 for the manual counts, and 20888 for the road tube counts. These results were used to calculate the errors for the RTMS and road tube data. The errors were found to be 2.85 percent low and .92 percent high respectively for the RTMS and the road tubes.

In the same manner, the totals for the southbound lanes were found. The traffic flow found by each system was found to be 23594 for the RTMS, 24365 for the manual counts, and 17054 for the road tubes. The errors were again calculated, and they were found to be 3.16 percent low and 30 low percent respectively for the RTMS and road tube data.

Finally, the overall totals were summed. The totals were found to be 43701, 45062, and 37942 respectively for the RTMS, manual counts, and road tubes. In addition, the errors were calculated to be 3 percent low for the RTMS data and 15.8 percent low for the road tube data.

Southbound: Day 2

Time	RTMS Counts	Manual Counts	Road Tube Counts
7:00	1332	1366	809
8:00	1056	1042	512
9:00	889	905	341
10:00	931	961	610
11:00	1004	1028	532
12:00	1059	1114	741
13:00	966	1070	398
14:00	1007	1128	386
15:00	1034	1161	404
16:00	1438	1503	672
Total	10716	11278	5405

Table 4

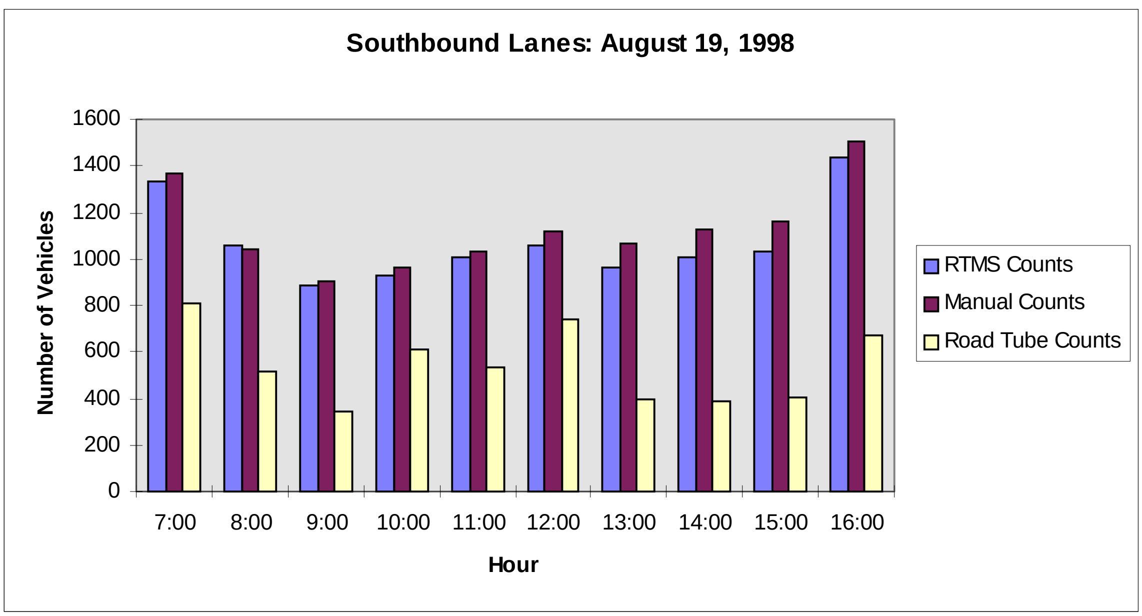

Figure 6

Task 8 *Determine the cost of installing inductive loops, and compare it to the cost of the non-intrusive system.*

Once the operation had been verified for the RTMS, it was necessary to compare the costs of installation for the RTMS and the inductive loops. Due to the fact that power and telephone lines, as well as counters, were needed for both systems, the costs for these items for each system were the same and were negligible when doing a cost comparison. Therefore, the costs for the RTMS and the inductive loops can be directly compared without any other factors involved.

Because the RTMS sensor can be used to count up to eight lanes of traffic, its installation cost would be the same for every roadway in South Dakota. The sensor, itself, costs $3300. Unless a new pole must be erected in order to mount the RTMS sensor, the material and labor costs for installing the sensor would most likely not exceed $300. This brings to total cost of installation to approximately $3600.

If it were necessary to conduct speed surveys on the roadway needing traffic counting, the RTMS could not be used. The Office of Data Inventory collects speed information on individual vehicles and then sorts the data. The data is used to find an average vehicle speed. In addition, the percentage of total vehicles traveling above certain rates of speed is found. The RTMS cannot report individual vehicle speeds, it can only determine the average speed over a period of time. This does not allow the vehicle data to be sorted on the basis of the speed of individual vehicles.

The cost of installing inductive loops depends on the roadway in which they are being placed. According to the Office of Data Inventory, the cost for installing inductive loops would be at least $500 per loop. One loop is needed for each lane in order to perform traffic counts. Additional loops may be needed in each lane if studies such as speed surveys are performed. This would double the total cost of installing inductive loops.

In order to determine the total cost of installing inductive loops, one must first determine the total number of lanes for the roadway. For instance, if loops are being installed on a four lane roadway, a total of four inductive loops would be needed to perform traffic counting. This would cost a minimum of $2000. If speed surveys were required for that same roadway, the number of loops needed would rise to eight. The total cost would also double to a value of at least $4000.

In general, inductive loops would be less expensive to install initially than the RTMS sensor for most roads in South Dakota. For the sites requiring speed surveys, the RTMS could not be considered for implementation.

There are some exceptions, such as "The Gap" in Rapid City, where it would be more expensive to install inductive loops. In addition, some roadways that have an extremely high volume of traffic, and it may not be desirable to install loops in the pavement. If the risk of closing lanes of traffic in these high volume situations is deemed greater than the price difference between the two systems, an RTMS sensor should be installed.

Task 9 *Review data and prepare recommendations for future implementation.*

The final task was to review data and prepare recommendations for future implementation. The Microwave Doppler sensor needed to be evaluated for both its cost effectiveness and its ability to record accurate traffic counts. Once all the data for costs and traffic counts had been collected and compared, recommendations were formed as to the conditions in which it would be advisable to implement the RTMS system.

Chapter 5

Findings and Conclusions

Once each of the tasks had been completed, it was necessary to produce findings and conclusions for the study. After reviewing all of the data, there were five basic findings and conclusions that resulted from this study.

- The testing showed the accuracy of the RTMS to be 3 percent low when compared to the manual counts.
- In general, inductive loops initially cost less than the RTMS.
- For sites requiring speed surveys, inductive loops must be installed.
- The life expectancy of the RTMS is approximately equal to that of undisturbed inductive loops.
- The RTMS has a distinct advantage because it is a non-intrusive system.

Finding 1 *The testing showed the accuracy of the RTMS to be 3 percent low when compared to the manual counts.*

Once again, the overall counts found in this study for the RMTS counts and the manual counts were 43701 and 45062 vehicles respectively. These values provide a percent error of 3 percent low when assuming the manual counts are correct.

According to the Office of Data Inventory, the accuracy of inductive loops, for the most part, depends on the counters through which they are connected. The sensitivity of the loops changes as they age. Therefore, it is necessary to adjust settings on the counter to compensate for the change in sensitivity. If this compensation is not made, the counts found via the use of inductive loops can become inaccurate.

Finding 2 *In general, inductive loops initially cost less than the RTMS.*

The cost of the RTMS sensor is $3300 per unit. On the other hand, inductive loops cost at least $500 per loop. Unless there is a road with at least seven lanes of traffic that needs inductive loops, the loops will initially be less expensive to install than the RTMS.

The lifetime cost of the inductive loops depends on several factors. First, one can determine the initial cost of the inductive loops by knowing how many lanes will need loops. Next, it must be determined whether or not maintenance involving sawing or resurfacing will be needed where the loops are to be installed. If maintenance is needed, the loops may need to be replaced, increasing the lifetime cost.

Finding 3 *For sites requiring speed surveys, inductive loops must be installed.*

When speed surveys are necessary at the counting site, the RTMS sensors cannot be implemented. This is due to the fact that the RTMS does not report the speed data in the manner required by the Office of Data Inventory. Rather than recording the speeds of individual vehicles, the RTMS finds the average speed of all the vehicles that passed through the detection zone over a period of time. This length of time can be set to be as short as ten seconds, but that still does not provide the information necessary to put the data in the format the Office of Data Inventory uses to report their speed surveys. Data Inventory requires that individual speeds be reported so that the counter can determine the average speed of the vehicles, as well as finding the percentage of vehicles which were traveling above a certain speed.

The inductive loops must be implemented for sites requiring speed surveys. The cost of installing inductive loops for speed surveys is double that of installing loops at the same site to merely count traffic. When speed surveys are performed using inductive loops, it is necessary to install two loops in each lane instead of just one for traffic counting. For example, a four-lane road would need eight inductive loops, and the cost would increase to $4000 for the installation of the loops.

Finding 4 *The life expectancy of the RTMS is approximately equal to that of undisturbed inductive loops.*

The life expectancy of inductive loops depends on whether or not the loops are disturbed while in the pavement. This disruption would be when the pavement is cut and/or removed during maintenance projects. An undisturbed inductive loop could last for 10 to 15 years. The life expectancy of a loop that has been disturbed depends on when the maintenance takes place.

According to publications provided by EIS, the mean time between failures for the RTMS unit is 90000 hours (10 years). This is comparable to the expectancy of an undisturbed loop. Therefore, a 10-year period can be used to configure a lifetime cost of the systems.

For a four-lane highway where speed surveys are not needed, the lifetime cost of an undisturbed system of inductive loops would be equal to the initial cost of $2000. If the pavement is cut or removed only once in each lane, destroying the loops that are present, over the ten years, the lifetime cost would double to $4000. Additional pavement repairs may increase the lifetime cost even further. Meanwhile, the lifetime cost of the RTMS will always equal its initial cost, barring some unforeseen incident.

Finding 5 *The RTMS has a distinct advantage because it is a non-intrusive system.*

Although the RTMS is generally more expensive than road tubes, the RTMS has a distinct advantage because it is a non-intrusive system. When inductive loops are being placed in the pavement, it is necessary to close the lane of traffic. Once the traffic is diverted, it takes approximately four hours to cut in a loop and give it time for the epoxy to set up. During that time, highway workers are put in danger by being exposed to traffic. In addition, those people travelling on the highway are being affected by the lane closures. Some may see it as a minor inconvenience, but others may have their opinion of the Department of Transportation diminished.

The RTMS sensor is better than the inductive loops in that it is a non-intrusive traffic sensor. The RTMS is mounted adjacent to the road rather than within it; and therefore, it is not prone to damage when maintenance is performed on the roadway. Additionally, the RTMS sensor does not require lane closure when being installed. This allows for faster installation time and less risk to workers.

Chapter 6

Implementation and Recommendations

The last portion of this report requires that implementations and recommendations be discussed. As a result of this study, one recommendation and two potential implementations were formed. These implementations and recommendations include:

- Further studies should be conducted during winter weather conditions.
- The RTMS can be implemented for traffic counting.
- Another potential use for the RTMS is for a mobile counting station.

Recommendation 1 *Further studies should be conducted during winter weather conditions.*

There is a need to conduct further studies on the traffic counting ability of the RTMS during winter weather conditions. As stated earlier, the Minnesota DOT and SRF Consulting Group, Inc. conducted a study of an RTMS unit which was a predecessor to the RTMS unit used in this study. They found that the RTMS tended to miscount vehicles following periods of rain and freezing rain due to water entering the housing. The housing for the RTMS used in this study was redesigned to prevent water from entering. Despite this, testing should be done during adverse weather conditions to ensure that the problems found in the Minnesota DOT study are not occurring for the RTMS installed on Interstate 229.

Another reason for testing the RTMS again during the winter months is to check if temperature affects the operation of the unit. EIS claims that the RTMS can operate normally in a temperature range of -37° C to 74° C, but it is still necessary to verify these claims via testing.

Implementation 1 *The RTMS can be implemented for traffic counting*

In order for a new traffic counting system to be implemented, it is important that the new system is compatible with the present system of collecting and storing data. If the systems were not compatible, it would be necessary to develop new software in order to place the traffic count data on the mainframe. Additionally, it would be necessary to purchase all new counters to operate the system through. This would vastly increase the overall cost of the new system.

Fortunately, the RTMS units can be operated through the same traffic counters as the present inductive loop systems. This means that the systems are compatible and can be implemented together. Because of this, the South Dakota Department of Transportation can implement the RTMS sensor at some counting sites while allowing inductive loops to remain at others. Due to this fact, a choice needs to be made as to which system should be installed at a particular site.

When it comes to the implementation of the Remote Traffic Microwave Sensor, two factors need to be taken into account. In order for the sensor to be feasible, it must count traffic accurately and be cost effective. The testing portion of this project showed that the RTMS produces accurate traffic counts. On the other hand, it was shown that the initial cost of the non-intrusive sensor was more than that of the inductive loops in most situations.

Four conditions need to be taken into account before a decision is reached whether to use inductive loops or the RTMS sensor. These conditions are the total number of lanes, whether or not speed surveys are required, the current pavement conditions, and the future maintenance plans for the roadway.

Number of Loops Needed

The number of lanes that need to be counted determines the minimum number of loops needed to be installed. For example, in this study the RTMS was tested on Interstate 229 in Sioux Falls, South Dakota. This particular road has four lanes of traffic; therefore, four inductive loops are needed for counting traffic.

The Office of Data Inventory claimed that the cost of installing inductive loops at this site would be approximately $500 per loop. This would provide a minimum cost of installation of $2000 for the loops at this site. This total is an initial cost not a lifetime cost.

The RTMS costs $3300 for each unit plus the cost of installation. In order to install the sensor, an RTMS cable is needed. This cable can be ordered from EIS for $200, or employees of the DOT can make it. Additional labor and materials needed for installation bring the total cost of installing the RTMS to be approximately $3600.

Speed Surveys

As stated earlier, the RTMS cannot be used if speed surveys are required. It is not compatible with the current requirements Data Inventory has for conducting speed surveys; therefore, the inductive loops must be implemented.

Current Pavement Conditions

Determining the current pavement conditions at the traffic counting site is very important when making the decision regarding which system to install. In order to install inductive loops, a higher grade of pavement integrity is required. If the pavement were poor and broken up, it would be virtually impossible to install the loops. In addition, if the pavement needed to be replaced in the near future, it would not make sense to install inductive loops just to have them destroyed a year or two later. In this case, it would be far better to install the RTMS unit.

If the pavement were in good condition, either system could be installed. Assuming that there are no maintenance projects planned for the section of road, the decision as to which system should be installed should be made considering only the number of loops needed. In general, this means that the installation of inductive loops would be more economically feasible.

Future maintenance plans

Future maintenance plans can be directly related to the current pavement conditions. It is very important to consider future maintenance plans while determining whether to install inductive loops or an RTMS sensor. If maintenance needs to be conducted in the future on the roadway that the counting system is located, it may be advisable to install an RTMS sensor. This would be most relevant for maintenance jobs that would require sawing and/or removing segments of the pavement. It is very easy for a maintenance crew to cut through inductive loops that are imbedded in the pavement. This would require that a new set of inductive loops be installed and would, therefore, increase its lifetime cost.

Overview of Implementation Factors

There are several situations in which it is more appropriate to install an RTMS sensor rather than inductive loops. First, if the cost for the RTMS is either less than or comparable to the cost of the inductive loops, the RTMS should be selected. The RTMS has shown to provide accurate counts, and it does not require lane closure. In addition, the installation of the RTMS does not put highway workers in danger from the oncoming traffic.

Next, if the pavement is in need of repair or replacement in the near future, it is more practical to install the non-intrusive sensor. As stated earlier, the cutting or removal of pavement severely reduces the life expectancy of the inductive loops and, therefore, increases its lifetime cost. Because the RTMS unit is located away from the pavement rather than within it, it is not affected by the repair or replacement of the road like the loops are.

Finally, there may be some situations that arise when inductive loops will be in need of replacement on high-traffic roads. If the potential risk to the construction crews for installing loops is deemed excessive and unnecessary, the SDDOT should consider installing the RTMS sensor even if the cost is greater than that of inductive loops. The safety of the workers should be held paramount.

Some scenarios exist in which it would make more sense to install inductive loops. First, if the pavement at the counting site is in excellent condition and if inductive loops are less expensive than the RTMS unit, it is advisable to install the inductive loops. It is very important that no maintenance requiring sawing or removal of pavement is needed in the vicinity of the loops over the next several years. If the inductive loops were destroyed once, it would double the lifetime cost of the loops. This increased cost would probably make it more feasible to install the RTMS.

The other situation that exists in which the inductive loops must be installed is when speed surveys are required at a counting site. The RTMS cannot be used for speed surveys due to the fact that the sensor does not meet the requirements of the Office of Data Inventory for reporting speed data.

An important idea to remember is that as long as they are working properly, the inductive loops can and should be left in the pavement to remain counting. There is no need for replacing them unless they are faulty and produce inaccurate counts.

Implementation 2 *Another potential use for the RTMS is for a mobile counting station.*

The Remote Traffic Microwave Sensor can be used for many different applications. According to EIS, the RTMS unit has been used for traffic counting, speed measurement, off-ramp metering and actuation, and incident detection. Some of these applications are unnecessary for South Dakota's roadways.

Traffic counting seems to be the application of the RTMS sensor that is the most suitable for the SDDOT. Since the use of the RTMS for permanent traffic counting sites was the main focus of this study, another type of counting will be explored. The RTMS would be a great tool for a mobile traffic counting system.

There are several reasons why the RTMS would be ideal for a mobile counting station. First, the sensor is portable. It can be moved from one location to another by removing the RTMS cable from the sensor, taking the sensor out of the bracket, moving the RTMS to its new location, and reconnecting the sensor to a bracket and to its cable.

Once it is in its new location, the RTMS needs to be calibrated. The settings for the sensor can be saved for each location and can be reinitialized once the sensor is returned to that location. This feature saves time in the setup process. If the location has not been used before, the setup process is quick. An experienced person can easily have the sensor installed and calibrated in less than one hour.

Next, the RTMS would also work well for a mobile counting station because the power required for the sensor could be generated from either a solar panel or a car battery. Both power sources are portable and relatively small. In addition, the RTMS can also be powered with an AC source. Therefore, if the RTMS is set up in an area where it is possible to run an extension cord to the sensor, it is possible to use that power source.

Finally, the RTMS is a non-intrusive sensor, so workers are not put at risk of setting it up on a high-volume roadway. Road tubes are currently being used for mobile traffic counting, and the workers setting them up must nail them down on the roadway. This puts the workers at risk, especially in high volume situations. When the workers feel that the risk is too great to set up road tubes, it would be beneficial if they had the option to set up the RTMS.

Because the RTMS is portable, is easy to calibrate, is non-intrusive, and can be operated with a variety of power sources, it is an ideal piece of equipment to use for a mobile counting station. The only problem that may occur with installing the RTMS for a mobile station is being able to get the sensor up to an acceptable height. A bucket truck may not always be available to the workers. If it is decided that the RTMS will be used for a mobile counting station, this problem needs to be addressed.