Truck Priority at Signalized Intersections

SEH No. A-MNDOT0326.00

December 15, 2004
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I hereby certify that this report was prepared by me or under my direct supervision, and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

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Truck Priority at Signalized Intersections

Prepared for Minnesota Department of Transportation

1.0 Introduction

Over the years, the Minnesota Department of Transportation (Mn/DOT) has developed a statewide network of inter-regional corridors (IRCs) that connect major population and production centers in the state. The vision for IRCs is that they will be connections that provide for the rapid movement of people and goods in a reliable manner. The travel time reliability factor has become increasingly important in the last decade due to the increasing number of businesses relying on time-critical freight service.

Non-freeway IRCs are particularly challenging in that many contain traffic signal-controlled intersections. By its very nature, a traffic signal introduces delay and travel time variability, and multiple traffic signals along a corridor magnify these effects.

Consequently, Mn/DOT has established a policy whereby the installation of additional traffic signals on these corridors should be avoided unless the signals address a specific safety problem. However, signalized intersections already exist in these corridors, and, inevitably, growth will occur, traffic patterns will change, and new traffic signals will be introduced in response to problems arising out of these changes.

In order to maintain the desired high level of service along a corridor, as the number of signalized intersections along that corridor increases, Mn/DOT will be challenged with improving the efficiency of each of those intersections. To address that challenge, Mn/DOT determined that providing some type of priority for truck traffic at signalized intersections is a concept that should be investigated.

Providing priority for trucks on IRCs could have several benefits. First, trucks are the primary vehicles traveling on the IRCs that are involved in time-critical freight delivery. Second, since the average severity of accidents involving trucks is significantly greater than the average severity of non-truck accidents, a method that aids truck drivers in passing through signalized intersections may have safety benefits. Finally, because truck characteristics include slow acceleration rates, it was believed that reducing the number of stops encountered by trucks could significantly reduce the
delays not only to the trucks themselves, but also to the vehicles following them.

This project involved the optimization of traffic signal timing parameters for an existing traffic signal system, followed by the development, installation, testing, and evaluation of a low-cost truck detection system designed to provide priority treatment for trucks at a signalized intersection. Through the course of this project, agencies outside the state of Minnesota were contacted to identify methods for providing truck priority, a site within Minnesota was selected, a truck detection and priority system was designed and installed, and before-and-after studies were conducted to determine the potential benefits for such a system.

2.0 Site Selection
Mn/DOT had a very specific set of criteria in mind for analyzing the benefits of truck priority at a signalized intersection. First, the intersection had to be located on an inter-regional corridor. Second, the composition of the traffic on the mainline had to be approximately 15 percent trucks, in order to maximize the potential benefits. Third, the intersection needed to be located within Mn/DOT’s Metro District (the Minneapolis/St. Paul area) to ensure sufficient resources could be mobilized, if needed. Fourth, to minimize the impact of adjacent signals, the intersection needed to be relatively isolated, with no other signalized intersections within several miles. Finally, the intersection could not be equipped with an advance warning flasher (AWF) system, which provides vehicles with notification upstream of a signalized intersection that the signal either is not currently green or will not be green when those vehicles reach the intersection. This last criterion was required so the AWF system would not mask or reduce the benefits of a truck priority system.

The anticipated benefits of a truck priority system were expected to be greater for a two-lane highway (one lane in each direction) than for a four-lane highway because other vehicles are generally unable to pass a slowly-accelerating truck on a two-lane highway that stopped or slowed down for a traffic signal. Unfortunately, no signalized intersection on a two-lane highway could be found that met all of the aforementioned criteria. As a result, the intersection of Trunk Highway (TH) 169 (a four-lane highway) and Laredo Street, in Belle Plaine, Minnesota, was selected by Mn/DOT.

Figure 1 shows the location of Belle Plaine relative to the Twin Cities, and Figure 2 is an aerial photograph of the subject intersection, with TH 169 shown as being a roadway oriented generally southwest to northeast.
Figure 1 – Location of Belle Plaine, Minnesota

Figure 2 – Aerial Photograph of TH 169 and Laredo Street, Belle Plaine, Minnesota
3.0 Literature, Research, and Implementation Review

As part of this project, Mn/DOT required a search of prior research or implementation of truck priority systems. The starting point for this process was the document identified in the RFP: “Truck Priority at Traffic Signals: Final Report”, prepared for Mn/DOT by SRF Consulting Group, Inc. in 2001. In addition to being provided on the CD submitted with this report, this document is available at the Mn/DOT web site at the following address:

http://www.dot.state.mn.us/guidestar/pdf/truckpriorityfinal.pdf

In its annotated bibliography, that report identified nine different information sources, dating back to 1962, concerning work pertinent to this project. Of those nine sources, three were published documents describing the “speed funnel” and were authored by Charles E. Dare, the developer of that concept; three were documents generated and describing the advance warning flasher program during its various stages in Minnesota, and two were presentations in 2001.

To augment these sources of information, SEH conducted a search using three different techniques. First, a conventional literature search of transportation libraries was conducted. Second, the department of transportation in each of the other 49 states was contacted via e-mail regarding any related research or implementation projects of which they were aware. Third, members of the Institute of Transportation Engineers (ITE) Traffic Engineering Council were also contacted, via its internet bulletin board (known as a “list-serve”) and queried regarding any knowledge they had of pertinent research or implementation. The text of the e-mail message to the departments of transportation and the text of the Traffic Engineering Council bulletin board message have been included in Appendix A and Appendix B, respectively.

As shown in Figure 3, of the 49 states contacted, 25 responded, representing a relatively high 51 percent response rate for this type of survey. From the figure, it is evident that responses were received from all parts of the country, as indicated by the fact that only one state neither responded nor bordered on another state that responded. Of those states responding, only the North Carolina Department of Transportation (NCDOT) indicated they had done any research or implementation of truck priority operations. Unfortunately, no research was available from NCDOT to indicate the effectiveness of their system, which they refer to as their “long vehicle detection system”, although anecdotal evidence indicates that NCDOT has been satisfied with the operation of their truck priority systems.
An additional seven responses were received from the ITE Traffic Engineering Council list-serve posting. Several of these respondents indicated they were aware of a research and implementation project in Texas jointly by the Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI) of The Texas A&M University System, College Station, Texas. Two reports were generated for this research and implementation project: “Reducing Truck Stops at High-Speed Isolated Traffic Signals” (Report 1439-8), in September 2000; and “Intelligent Detection-Control System for Rural Signalized Intersections” (Report 4022-2), in August 2002. As with the document mentioned earlier, copies of these documents are included on the CD for this project. In addition, these documents are available on the TTI web site, at the following addresses:

http://tti.tamu.edu/product/catalog/reports/4022-2.pdf

The implementation of the truck priority system in Texas is also reflected in Figure 3.
3.1 Summary of Truck Priority System Operations in North Carolina and Texas

The truck priority systems implemented both in North Carolina and in Texas utilize similar strategies and philosophies. In both cases, a two-loop configuration is used in each lane for which priority operation is desired. These loops are installed a fixed short distance apart, several hundred feet upstream of the signalized intersection’s stop line.

As vehicles drive over the pair of loops, a device in the traffic signal cabinet uses the differences in activation times and the loop occupancy information to determine vehicle speed and classification. In North Carolina, the device in the controller cabinet is a special vehicle detector amplifier/classifier. In Texas, the device in the cabinet is also special vehicle detector/classifier, but which is linked to an industrial-grade Pentium personal computer (PC) located in a separate cabinet, immediately adjacent to the controller cabinet. Although the devices are different, the manner in which they adjust the signal timing in response to a heavy commercial vehicle is the same.

If it is determined by the firmware in the North Carolina special detector amplifier or by the software in the Texas computer that the vehicle detected is a truck and it would benefit from an extended green indication, the device places a phase hold on the phase serving the truck movement for a user-determined period of time sufficient to allow the truck to pass through the intersection.

In North Carolina, truck priority systems have been in place and in use for more than 17 years – the tenure at NCDOT of the individual currently responsible for its implementation and operation. The original request for implementation of truck priority was originated by NCDOT, rather than the trucking industry. Truck priority is used as a safety measure primarily at isolated signalized intersections where downgrades and high speeds exist. Unfortunately, as indicated earlier, the contact at NCDOT is unaware of any before-and-after studies conducted on their truck priority system.

In Texas, the anticipated benefits of implementing a truck priority system were: reduced pavement wear, reduced delays to trucks, reduced delays to other vehicles due to reduced truck stops, reduced delays to other vehicles due to green extensions triggered by trucks, reduced fuel consumption and emissions, and potentially reduced brake and tire wear, though these last two measures would be difficult to quantify. TTI conducted the before-and-after study after several technical challenges were overcome. The challenges included several malfunctions with the detector amplifier/classifier hardware and non-user-friendly PC software. These challenges were overcome by working with the hardware supplier and by TTI rewriting the PC software. Although several additional problems (construction, controller flash operations, and failed detectors) prevented TTI from obtaining the desired quantity of “after” data, it was estimated that on one approach of their test site the truck priority system could eliminate stops for approximately 100 of the approximately 2,500 trucks arriving on that approach each week.
3.2 Research Review Conclusions

A primary conclusion of the literature search and the surveys is that there has not been a great deal of research done on the topic of truck priority systems. Only two research papers were found that were not identified in the 2001 Mn/DOT study, both published by TxDOT and TTI after the literature search for that project. Those papers are noteworthy because they document the implementation and effectiveness of a truck priority system. It appears from those papers that some benefits to trucks can be derived from a priority system. Even for the modest truck volumes at their test intersections (2,500 trucks per week), it was determined the cost of installing the system would be offset by the benefits to truck traffic in about two years.

Although there has not been much research into the subject of truck priority, this project has identified there is some interest among the various state agencies. Six of the twenty-five respondents to the information survey requested a summary of findings when the project is complete. As with the responses to the survey itself, the requests came from across the country: Connecticut, Iowa, Nevada, North Dakota, Ohio, and West Virginia.

4.0 Traffic Signal Controller Settings

Traffic signal controller settings were examined for two reasons. First, because several years had passed since the installation of the traffic signal system at this intersection, the controller timings potentially did not reflect current Mn/DOT signal timing practices. Consequently, a comparison of in place signal timings and Mn/DOT standards was conducted.

Second, there was a desire to determine if signal timing changes alone could provide benefits to trucks without a truck detection and priority system implementation. In addition, the development of optimized signal timings prior to implementation of the truck detection and priority system would allow for a separate determination of the benefits of a truck priority system and the benefits of altered signal timing.

Table 1 below shows the basic signal timing parameters that were in place (Alternative A) at the beginning of the project and the signal timing parameters that were tested for 11 other alternatives.
Table 1
Traffic Signal Controller Settings for TH 169 Through Movements

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Max Green</th>
<th>Min Green</th>
<th>Veh Extension</th>
<th>ABAI</th>
<th>Max Initial</th>
<th>Time To Reduce</th>
<th>Min Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – Before</td>
<td>100</td>
<td>20</td>
<td>6.0</td>
<td>8</td>
<td>40</td>
<td>60</td>
<td>3.0</td>
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<td>B</td>
<td>120</td>
<td>30</td>
<td>6.0</td>
<td>8</td>
<td>40</td>
<td>80</td>
<td>3.0</td>
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<td>6.0</td>
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<td>40</td>
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<td>6.0</td>
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<td>47</td>
<td>60</td>
<td>5.9</td>
</tr>
</tbody>
</table>

As can be seen in Table 1, the variables that were tested included mainline maximum green time, ranging from 30 seconds to 150 seconds; mainline minimum green time, ranging from 15 to 30 seconds; mainline vehicle extension time, which was either 6.0 or 6.8 seconds; actuations before added initial (ABAI), which was tested at 8 and at 13 vehicles (depending on minimum initial); maximum initial, ranging from 30 to 47 seconds; time to reduce, ranging from 45 to 100 seconds; and minimum gap, ranging from 3.0 to 5.9 seconds.

When compared to current Mn/DOT signal timing standards, it was found that the vehicle extension time (6.0 seconds) at the beginning of the project was less than the standard (6.8), as were the maximum initial (40 versus 47 seconds), and the minimum gap (3.0 versus 3.8 seconds). In fact, the programmed minimum gap of 3.0 seconds would have the undesirable effect of placing a vehicle traveling at the speed limit near the center of the “dilemma zone”, which is described later in the Functional Requirement Specification. It is believed that many of the timing discrepancies are a result of the extension detectors being placed 550 feet from the stop line (consistent with Mn/DOT policies for a 60 mph roadway) rather than 475 feet from the stop line, as recommended for a 55 mph roadway.

Different values for cross street (Laredo Street) and mainline left turn phase timings were not tested, since they met current Mn/DOT standards and they were not the movements that were expected to experience the benefits of the truck priority system.

The testing and iterative optimization was conducted using the CORSIM simulation package. Most of the alternative sets of timing incorporated some modification from the previously existing timings to a value consistent with Mn/DOT signal timing policies. For each alternative set of timings tested, the average of the measures of effectiveness for 20 different simulations was calculated. As indicated in the table, the signal timing parameters associated with Alternative J provided the best overall operation of those alternatives.
tested. This alternative incorporated timings consistent with current Mn/DOT standards for maximum initial and for minimum gap, but used a greater minimum initial time of 30 seconds, compared to the Mn/DOT standard for this intersection configuration of 20 seconds.

5.0 Truck Detection and Priority System Specifications

Using information obtained from previous research and implementation activities, and in discussions with Mn/DOT’s state and district traffic signal engineers, SEH developed design and operational standards for a low-cost truck detection and priority system, as well as a specific design for the intersection of TH 169 and Laredo Street.

The following specifications were developed:

1. A Functional Requirement Specification, which describes the general functionality of the truck detection and priority system.

2. A Technical Requirement Specification, which describes the necessary equipment and signal controller cabinet modifications required to implement the truck detection and priority system.

3. An Operational Requirement Specification, which provides recommendations concerning the operation, geometric requirements, and applications of truck detection and priority systems.

4. A Maintenance Requirement Specification, which provides recommendations specific to maintenance of the truck detection and priority systems.

These requirement specifications are presented here in their entirety and have been included as four separate documents on the project CD submitted with this report.

5.1 Functional Requirement Specification

This specification describes the general functionality of a truck priority system, as implemented at the intersection of TH 169 and Laredo Street in Belle Plaine, Minnesota.

Essentially, the purpose of the truck priority system is to provide a greater likelihood that larger commercial vehicles (tractor-trailers) arriving on selected approaches to a signalized intersection will not be stopped at the intersection, and, if they are stopped, the truck driver will be less likely to be caught in the “decision zone” (or “dilemma zone”) when the signal changes from green to yellow. The “decision zone” is that area upstream of an intersection where it is most difficult for drivers to determine whether they can and should continue safely through the intersection during the yellow clearance or they should begin braking because they will be unable to enter the intersection prior to the display of the red indication. Figure 4 shows the decision zone dimensions provided in the Mn/DOT Traffic Signal Timing and Coordination Manual.
Figure 4 – Decision Zone Locations at Various Speeds
(Source: Mn/DOT Signal Design Manual – February 2003)

NOTE: Grades and other factors may require adjustment from normal placement.
Detector spacing outside the limits shown may require additional detectors.
The truck detection system, which places a call to the controller only when a long vehicle is detected, is located upstream of existing phase extension detection. Through an advance call to the controller placed when a truck passes over it, the additional detection provides additional green time for an approaching truck to reach the conventional extension detector.

With the truck priority system, heavy commercial vehicles approaching the intersection are detected through the truck detection system, which places a request for service in the traffic signal controller, the device controlling the traffic signal indications at the intersection. If the signal indication is already green for the approach on which that vehicle is arriving, the controller will extend the green indication for the truck a predetermined amount of time (green extension) unless the maximum green time for that movement has been or would be exceeded by the requested green extension. The green extension time provided for a truck detection is determined by the conventional controller settings; i.e., the duration of the green extension will be the programmed vehicle extension time for that vehicle phase, or, if volume-density operation is implemented, the duration will lie somewhere in the range between the programmed vehicle extension time and the programmed minimum gap time.

The functionality of this truck priority system is different than the functionality of the truck priority systems implemented both in North Carolina and in Texas. In both of those applications, a device external to the controller (a special detector amplifier/classifier in North Carolina, an industrial PC in Texas) issues a hold on the phase serving the truck movement. Issuance of a phase hold causes the controller to ignore the maximum green time programmed, allowing the controller to exceed times the engineer determined should not be exceeded. In a worst-case scenario, a device failure (either hardware or software) could cause a constant hold to be placed on a given phase, indefinitely locking out service to any conflicting phases – cross street or opposing left turn.

Due to this possibility, however remote, the truck priority system for this project does not use the phase hold inputs to the controller. Instead, the truck detectors simply act as additional conventional call-and-extend detectors for the phase serving the truck movement. The truck detectors merely extend the green time for trucks to travel from the truck detectors to the conventional extension detection provided for all vehicles, and those conventional extension detectors are relied upon to provide sufficient time for the truck to pass through intersection. Because maximum green times programmed into the controller are still in effect, a truck detection or (worse) a truck detector failed in a locked-on state will not cause the controller to ignore calls for opposing phases. Although a failed, locked-on truck detector will extend the phase serving the truck movement to its maximum every cycle, resulting in longer delays vehicles served by opposing phases, this failure mode is safer than that used in the North Carolina and Texas truck priority systems.

5.2 Technical Requirement Specification

This specification describes the equipment necessary and cabinet modifications required to implement truck priority systems similar to the
system installed at the intersection of TH 169 and Laredo Street in Belle Plaine, Minnesota.

5.2.1  Inductive Loops vs. Microwave vs. Video Detection

In each lane in which priority operation is desired, two standard 6-foot by 6-foot loop detectors are installed, with a 30-foot separation between loops, upstream of existing vehicle phase extension detection. The 30-foot distance does not have to be precise, as is required by some applications for calculating speed measurements and determining vehicle classifications. Thirty feet, plus or minus five feet, should be sufficient. The basis for the 30-foot separation is described in the Operational Requirement Specification. A pair of loop detectors was preferred over other types of vehicle detection, although other types of detection systems were considered. Microwave detection was eliminated as a possibility due to its inability to place or not to place calls to the traffic signal controller based on vehicle classification. Being able to discriminate between classes of vehicles (heavy trucks versus passenger vehicles) and place calls to the controller only for trucks is essential to the effective operation of the truck priority system. Video detection systems can discriminate between classes of vehicles and place calls to the controller based on vehicle classification. However, the estimated cost of installing video detection was significantly higher than the loop detector installation selected, and minimizing installation costs was one of the goals in designing the system.

5.2.2  Cabinet Wiring Modifications

In simplified terms, the manner in which loops normally send calls to the traffic signal controller is through detector amplifiers in the controller cabinet. One or more loops are connected to a detector amplifier, the output of which is +24 volts DC (VDC) to the controller when no loops connected to the amplifier are occupied and 0 volts (logic ground) when a loop connected to the amplifier is occupied.

Figure 5 and Figure 6 show schematically how the amplifier changes the signal it sends to the traffic signal controller. Both +24VDC and logic ground are inputs available to the detector amplifier, as shown entering the left side of the detector amplifier in both figures. When a vehicle is detected by the amplifier, the amplifier internally switches its connection to the controller from the +24VCD input (Figure 5) to the logic ground input (Figure 6).
Figure 5 – Schematic of Conventional Detection with Loop Unoccupied

- DETECTOR
- AMPLIFIER
- +24VDC
- LOGIC GRD

OUTPUT TO CONTROLLER
(+24VDC)
NO PHASE CALL
For the truck detection system, the desired output to the controllers is logic ground to the controller only if both loops are occupied simultaneously. To accomplish this, each loop detector in each pair of truck detection loop must be connected to a separate detector amplifier channel. The two detector amplifier channels corresponding to the two loops in the same lane are connected in series, such that the output of the first detector amplifier channel is used as the normally-logic-ground input to the second detector amplifier channel, as shown schematically in Figure 7 through Figure 11.
Figure 7 – Schematic of Truck Detection and Priority System with No Loop Occupied

Figure 7 above illustrates the case in which neither the upstream loop nor the downstream loop of the truck detector loop pair is occupied. Because the downstream loop is unoccupied, the contact between the controller output and the normal +24VDC input to the downstream detector channel is closed; therefore, the output to the controller is +24VDC, and no call is placed to the phase for that movement.
Figure 8 above illustrates the case in which the upstream loop is occupied, but the downstream loop is unoccupied. Again because the downstream loop is unoccupied, the contact between the controller output and the normal +24VDC input to the downstream detector channel is closed, and the output to the controller is +24VDC. Once again, there is no call to the phase serving that movement.
In Figure 9 above, the smaller vehicle has advanced and is now between the two detectors comprising the truck detection system. This is made possible by the 30-foot spacing between the trailing edge of the upstream loop and the leading edge of the downstream loop. As in Figure 7, because neither detector is occupied, the +24VDC input connection on both channels is closed, and no call is placed to the phase serving the approach shown.
Figure 10 illustrates the case in which the downstream loop is occupied, but the upstream loop is unoccupied. Because, the upstream loop is unoccupied, the output from the upstream detector channel is +24VDC. Consequently, both inputs to the downstream detector channel are +24VDC; therefore, regardless of the switch position for that channel, the output to the controller will be +24VDC, and no call is placed for the phase serving that movement.
Finally, Figure 11 illustrates the only one of the four truck detection system cases in which the system sends a logic ground signal to the controller. Occupation of the upstream detector passes a logic ground signal from the upstream detector channel to the lower input terminal (as shown in the figure) of the downstream detector channel. With the downstream loop also occupied, downstream detector channel closes the contact between that terminal and the controller output, and a vehicle actuation for that phase is placed in the controller.

5.3 Operational Requirement Specification

This specification provides recommendations concerning the operation, geometric requirements, and applications for truck priority systems at signalized intersections in Minnesota. These recommendations are based on Mn/DOT signal operations guidelines and experiences and observations pertaining to the implementation of the truck priority system at the intersection of TH 169 and Laredo Street in Belle Plaine, Minnesota.

In each lane a truck detector system, consisting of two loop detectors spaced 30 feet apart, is installed upstream of the existing phase extension detector.

5.3.1 Separation of Loop Detectors in the Truck Detection System

For the 55 mph approaches of the test intersection, the 30-foot separation between loops was selected based on three competing considerations.
First, the separation between loops had to be of such size that a large commercial vehicle (i.e., a tractor-trailer) would occupy both loops simultaneously. This was required because a call for service is sent to the controller only when both loops are occupied. For all tractor-trailer standard configurations as defined by AASHTO (e.g., WB-40, WB-50, etc.), a 30-foot separation between loops tends to place the downstream loop of the truck detection pair directly under or in close proximity to at least one axle of the tractor at the same time that the upstream loop of the pair is directly under or in close proximity to at least one axle of the trailer.

Second, separation between the loops has to be large enough such that only vehicles with trailers will typically occupy the detectors simultaneously. This factor tends to encourage larger separations between the loops. A 30-foot separation between loops eliminates most single-unit trucks, while this separation allows for detection of nearly all tractor-semi-trailer vehicles – the vehicles that experience the greatest acceleration and deceleration delays. There were some observations of non-commercial vehicles with trailers (e.g., a personal pickup truck with a boat trailer) being detected as trucks, but the frequency of such occurrences was small, and the potential benefits to smaller commercial tractor-trailer vehicles are believed to outweigh the efficiency impact of false calls by these personal vehicles. Shortening the separation between the loops would increase the likelihood of false commercial vehicle calls, due to the increased probability of a shorter vehicle occupying both truck detection system detectors at the same instant.

Third, separation between the loops has to be small enough such that false calls due to two separate vehicles occupying the two truck detectors simultaneously (two vehicles, each occupying only one of the pair of detectors) are minimized. This factor tends to encourage smaller separations between the loops. With the pair of 6-foot loops separated by 30 feet, the required distance between vehicles to avoid simultaneous activation is approximately 42 feet (30-foot separation + 2 loops * 6 feet/loop). For a speed of 55 miles per hour (mph), the 42-foot distance corresponds to a headway between vehicles (rear of one vehicle to the front of the following vehicle) of 0.52 seconds, a value well below the recommended safe following headway of 2 seconds. Even with vehicles traveling at 30 mph – a possibility as vehicles are slowing down as they approach the rear of a queue – the headway between vehicles would need to be 0.95 seconds. As the separation between the loops increases, the potential of false commercial vehicle calls also increases due to the increased probability that two separate vehicles will occupy the two detectors in the truck detection system.

5.3.2 Distance of Truck Detection System from Conventional Extension Detectors

According to the RFP for this project, trucks “by law are required to maintain a 300-foot distance from vehicles they are following.” This 300-foot distance corresponds to a time headway between the leading vehicle and the following truck of 3.4 seconds at 60 mph and approximately 4.5 seconds at 45 mph.
While extension intervals on Minnesota trunk highways frequently start in the 6- to 7-second range, to maintain an efficient and responsive operation, Mn/DOT signal timing policies encourage gap reduction to levels in the 2- to 4-second range – depending on a number of factors. Obviously, if a truck is following at the required distance, at the lower extension times the signal will gap out before the truck can reach the extension detector, and the truck will be required to stop. In effect, this combination of law and timing strategy penalizes the truck driver for obeying the law.

The strategy of the truck detection system is to prevent the signal from gapping out just as a truck is approaching. This is accomplished by detecting the approaching truck and extending the green time sufficiently for the truck to reach the conventional extension detector. A number of factors contribute to the determination of the distance upstream of the normal phase extension detector at which the truck detection system should be placed. These factors include the minimum recommended following distance for trucks (300 feet, as indicated above), the range of vehicle speeds desired to be covered, and signal timing parameters, specifically the minimum gap time.

The first step in determining the distance of the truck detection system from the conventional detectors is to determine the maximum likely gap between a vehicle and a truck following that vehicle at the minimum following distance. To calculate the maximum likely gap, use the following formula:

\[
\text{Gap}_{\text{max}} = \frac{\text{MFD}}{(1.47 \times (\text{PSL} - 10))}
\]

Where:
- \( \text{Gap}_{\text{max}} \) = maximum gap, in seconds,
- \( \text{MFD} \) = minimum following distance, in feet, and
- \( \text{PSL} \) = posted speed limit, in miles per hour.

The 2001 Mn/DOT study recommended using a value 10 miles per hour below the posted speed limit (i.e., “PSL – 10”) for the minimum recommended speed at which priority for trucks be provided.

For the project intersection in Belle Plaine, the minimum following distance is 300 feet, as dictated by state law, and the posted speed limit is 55 miles per hour. These values lead to a maximum likely gap of 4.5 seconds.

The next step in the distance determination is to calculate the shortfall, if any, of the existing signal timing in providing an adequate gap for the following truck. In this case, the minimum gap timing set in the controller was 3.0 seconds, creating a potential gap of 1.5 seconds. In other words, with pre-project controller settings, a truck traveling at 45 miles per hour (66 feet per second) and following another vehicle at the minimum lawful distance of 300 feet would reach the extension detector 1.5 seconds after the green extension for the leading vehicle has timed out. Even if traveling at the speed limit (55 mph), there would have been a shortfall of 0.7 seconds, and the traffic signal would change to yellow just before the truck reaches the extension detector.

Once a shortfall has been determined, a course of action needs to be identified. If the shortfall itself is greater than the minimum gap timing, the minimum gap timing must be increased (and the shortfall recalculated) at least to the point where the minimum gap timing and the shortfall are equal.
Once the shortfall is less than or equal to the minimum gap timing, the distance of the truck detection system upstream of the existing extension detection should be located somewhere between \( D_{\text{min}} \) and \( D_{\text{max}} \), where \( D_{\text{min}} \) is the distance traveled by a truck during the shortfall time and \( D_{\text{max}} \) is the distance traveled by a truck during the controller’s minimum gap timing. These values are calculated as follows:

\[
D_{\text{min}} = S_{\text{fall}} \times 1.47 \times (\text{PSL} - 10), \quad \text{and} \\
D_{\text{max}} = \text{CMG} \times 1.47 \times (\text{PSL} - 10),
\]

\( S_{\text{fall}} \) = shortfall, in seconds,
\( \text{PSL} \) = posted speed limit, in miles per hour, and
\( \text{CMG} \) = controller’s minimum gap timing, in seconds.

For the Belle Plaine intersection, the range of distances within which the truck detection system should be placed was between 99 feet and 198 feet upstream of existing extension detectors. A distance of 150 feet, the approximate midpoint of the two distances, was selected. Figure 12 shows the dimensions on each approach of TH 169 to Laredo Street.

**Figure 12 – Locations of Loop Detectors on TH 169 Approaches**

![Diagram of Loop Detectors](image)

Note: If a shortfall is identified, another course of action is to increase the minimum gap setting in the controller by at least the shortfall time. The advantage of this course of action is that a truck detection system would not be necessary to extend the green for a following truck, since the gap between a vehicle and a following truck is accommodated entirely within the minimum gap timing. The disadvantage of this course of action is that the green time may be extended unnecessarily whenever a truck is not present, potentially delaying traffic on other approaches to the intersection.

### 5.4 Maintenance Requirement Specification

This specification provides recommendations concerning the maintenance of truck priority systems at signalized intersections in Minnesota. These maintenance recommendations are based on experiences and observations pertaining to the implementation of the system at the intersection of TH 169 and Laredo Street in Belle Plaine, Minnesota.
If constructed as indicated in the Technical Requirement Specification, as two conventional inductive loop detectors whose detector amplifiers are connected in series in the traffic signal control cabinet, maintenance requirements should be the same as for conventional inductive loop detectors.

The only difference between conventional loop detectors and the truck detection system concerns how calls are placed in the controller. The truck detection system requires that both loops be occupied before a call is placed in the controller. Because this difference does exist, there should be a notation in the traffic signal cabinet and/or maintenance personnel should be aware that the truck detection system is in place.

Having stated that no extraordinary maintenance is required for truck detection systems, it should be noted that verifying the truck detection system is working properly can be accomplished by one person but is much easier with two. In the verification process, the two-person team usually consists of the first person watching the individual amplifier channel indicators for the two-loop system and the second person watching the controller inputs. Only when both channel indicators are activated should a detection be registered in the controller.

### 6.0 Stop and Delay Study Results

Vehicle stop and delay studies were conducted for three different scenarios: the pre-project signal timing scenario, the project-optimized signal timing scenario without truck priority, and the project-optimized signal timing scenario with truck priority. The studies for the three scenarios were conducted within days of each other in order to minimize the effects of seasonal variations in traffic flow and traffic composition.

In addition to conventional stop and delay measures of effectiveness being collected, the following additional information was gathered: average cycle lengths of the full-actuated intersection (cycle length measured as the time between consecutive occurrences of start of concurrent mainline through green), classification of vehicles at front of queue, and the likelihood of a truck being at the front of the queue in the right lane. Mn/DOT expressed a specific interest in determining whether or not the truck detection and priority system reduces the probability that a truck will be the front vehicle in the queue when the signal changes from red to green, because any vehicles located behind the truck are further delayed by the truck during the early stages of the green signal indication if they are unable to pass the truck. Observations during the project revealed a tendency for truck drivers to remain in the right lane at this intersection; consequently, information was gathered for queues in the right lane.

Initial studies were conducted in December 2003, but the data obtained during those studies revealed significant variations in the volumes both of trucks and of vehicles in general, and the variations in volume affected the results. In addition, it was determined the percentages of vehicles that are trucks during December is low relative to most of the rest of the year.
For those reasons, a second evaluation of the three scenarios was conducted in August 2004, a month during which truck traffic levels are elevated. The following figures show the results of those studies. In those figures, the three scenarios are identified as “Before”, which is the pre-project signal timing scenario; as “Modified Timing”, which is the scenario with optimized timing but no truck priority; and as “Truck Priority”, which is the scenario with both optimized timing and truck priority active. Also in these figures are results for northeastbound TH 169 are labeled as “Mainline NB” and for southwestbound TH 169 are labeled as “Mainline SB”. Results for Laredo Street have been labeled as “Cross Street”.

Figure 13 – Percentages of Vehicles Stopped for All Scenarios

In Figure 13, the effects of the truck priority system on the composition of stopped vehicles can be seen. When comparing the results for the before-and-after truck priority implementation, the charts show that, overall, the percentage of mainline vehicles stopping at the signal is essentially the same before (“Modified Timing”) and after (“Truck Priority”) the implementation of the truck priority system. The exception is the perceptible increase for the northbound direction during the afternoon (PM) peak period, where the percentage of all vehicles stopped increases from 38 percent to approximately 44 percent.

On the other hand, the percentages of trucks stopping declines when truck priority is implemented, by several percent in the morning and midday peak periods and slightly during the afternoon peak period. This is an indication that the truck priority system has been successful in at least one of its goals – reducing the percentage of trucks required to stop.

The reduced impacts during the afternoon peak period (relative to the other time periods) can be seen in nearly all of the studies. The primary reason the
impacts are reduced during this time is the higher volume present. Higher overall volumes mean that the traffic signal green indications are likely to be extended by passenger vehicles, which in turn also benefits trucks. This is especially true since each mainline approach contains two through lanes, where passenger vehicles in the left lane can extend the green indication to benefit trucks traveling primarily in the right lane.

One other observation of note from the charts in Figure 13 is that for all scenarios and all time periods, the percentage of trucks stopping is less than the percentage of all vehicles stopping. While the reasons for this are not obvious from the data, field observations during the studies revealed that truck drivers are generally better than the average passenger vehicle driver in anticipating the signal indications as they approach the intersection. Because the mainline signals were visible in both directions for over a half mile, truck drivers tend to begin to decelerate slowly well in advance of the intersection by “coasting” when they see a red light ahead, whereas passenger vehicle drivers tend to decelerate faster (using their brakes), but much closer to the intersection when presented with a red light. More than likely, this characteristic of truck drivers arises from the realization that slowing well in advance of a red light is less likely to result in a stop, from which a truck will accelerate very slowly.

Figure 14 and Figure 15 show the results of the delay study. Figure 14 shows the average delay per vehicle, while Figure 15 shows the average delay per stopped vehicle. Perhaps the most significant findings shown in these figures are that the same benefits to trucks seen in the stop study do not carry over to the delays. In spite of a reduced likelihood that trucks will be stopped at the signal, they experience a slight increase in the average delay per vehicle, specifically because the average delay per stopped truck increases.
The reason for the increase in average delay per stopped truck is not obvious until the results of Figure 16 are examined. In that figure, it is revealed that as truck priority is implemented, the average actuated cycle length of the intersection increases. This phenomenon is the direct result of providing more green time for the mainline direction, as in the “Modified Timing”...
scenario, providing even more green time for the mainline direction when trucks are present under the “Truck Priority” scenario.

Providing additional green time for the mainline direction corresponds to providing more red time for the cross street (and mainline left turn) movements. Longer red times for those movements translate into larger queues on red for those movements, and serving larger queues also requires more green time for those movements when there signal does change to green. Consequently, providing more green time for the mainline through traffic and trucks also equates to longer green times for the other movements. Since all movements on average receive more green time, the average cycle length must increase, and longer cycle lengths, in general, lead to longer average delays.

If the cross street and mainline left turn movement green times had been held low artificially – by lowering the maximum green time values for those movements – mainline delays could have been reduced, but complaints would be expected from drivers of the other movements.

**Figure 16 – Average Cycle Length for All Scenarios**

The final measures of effectiveness for which data were collected dealt with the composition of vehicles at the front of the queue when the signal changes from red to green for the mainline through movements. Figure 17 shows the results for both lanes on both mainline approaches. Because the focus of the studies was to identify benefits of the truck priority system, these studies were not conducted for the pre-project signal timing for the morning and midday peak periods. Afternoon peak period data was collected because an additional person was available during that period. It can be seen in that
figure that often there is no queue in at least one of the lanes when the signal changes to green, especially during the midday peak period. In addition, with the implementation of truck priority, the likelihood that a truck is the front vehicle in the queue decreases.

Figure 17 – Profile of Vehicles at Front of Queue at Start of Green

![Vehicle at Stop Bar at Start of Green](image)

This trend is shown better in Figure 18, where only the rightmost through lane is examined, and only those cycles where a queue is present at the start of green are included. This figure shows a modest reduction in the likelihood that the front vehicle in the queue will be a truck when truck priority is implemented. The fact that a reduction occurs is not surprising, since the truck priority system is designed to expedite the passage of trucks through the traffic signal. The fact that the reduction is modest, and not more significant, is also not surprising, since the truck priority system is designed to provide benefit only to trucks following other vehicles just beyond the minimum lawful following distance. Since the majority trucks may be following closer or significantly farther than that distance, all trucks will not benefit.
7.0 The “Speed Funnel”

The final alternative analyzed as part of this project was the feasibility of and the potential offered by the “speed funnel”, which is a concept presented in a research paper in the early 1970s. The basic idea behind this concept is to provide information to drivers in advance of a traffic signal, indicating to those drivers the speed at which to travel to arrive at the signal during a green indication. Such a system was anticipated to provide benefits to trucks and passenger vehicles alike, since the messages would be displayed to all vehicles.

Basically, it was proposed that a variable message sign (VMS) be placed some distance upstream of the traffic signal on which would be displayed messages such as “SIGNAL TIMED FOR 50 MPH”, “45 MPH FOR GREEN AT SIGNAL”, or “PREPARE TO STOP” if the speed at which a vehicle would need to travel for a green indication is slower than 10 mph below the posted speed limit. Figure 19 shows a sketch of the proposed speed funnel system.
The February 2001 Mn/DOT study referred to earlier in this report generated the following basic guidelines for the speed funnel concept: a one-half mile distance from the signalized intersection’s stop line upstream to the variable message sign, and no advisory speed limit less than 10 mph below the posted speed limit due to safety concerns associated with drivers reactions to the advisory speed. No specific messages were identified, but some recommendations were made, including the “PREPARE TO STOP” message when the advisory speed limit is lower than the threshold.

Using the Belle Plaine intersection as the basis in determining the values of the key speed funnel parameters, it was determined that messages would be displayed if vehicles could travel 45 mph, 50 mph, or 55 mph (the speed limit) and receive a green light at the intersection. With a one-half mile distance from the VMS to the stop line, those speeds correspond to travel times of 40 seconds, 36 seconds, and 32 seconds, respectively.

In order to display the proper message, the start of green for the mainline through movement would need to be known at least 40 seconds in advance – the travel time at 45 mph. In order to display the “PREPARE TO STOP” message at the appropriate time, the end of green for the mainline through movement would also need to be known 40 seconds in advance. This 40-second advance notice would need to be consistent and, therefore, would...
require that the cross street and mainline left turn signal phase durations be known at all times. Since the existing full-actuated operation would not provide a consistent 40-second advance notice, the traffic signal would need to operate in a pre-timed fashion.

The minimum 40-second advance notice time is further complicated by the potential of queues being present at the intersection at the start of green. More than 40 seconds notice would need to be provided, and significant intelligence incorporated into the traffic control system, to accurately predict the times at which a queue may dissipate after the start of green. In addition, for liability reasons, any form of emergency vehicle preemption at the signalized intersection would need to be disabled or, at best, severely restricted so that a vehicle traveling at the VMS advisory speed would not arrive on a red light due to preemption.

Assuming that a pre-timed operation is satisfactory, the speed funnel timing parameters to be determined are the durations of each of the messages. For the Belle Plaine intersection, it was previously determined that travel times of 32, 36, and 40 seconds correspond to the three advisory speeds that could be displayed on the VMS. Therefore, as the signal cycles toward the beginning of the mainline green indication, 40 seconds prior to the start of green, the 45 mph advisory speed could be displayed; at 36 seconds prior to the start of green, the 50 mph advisory speed could be displayed; and at 32 seconds prior to the start of green, the 55 mph advisory speed could be displayed. As a result, the first two messages would each be displayed for only about 4 seconds.

Because the speed funnel system would require a pre-timed operation, because the advance notification time would need to be adjusted based on queue detection intelligence at the intersection, because emergency vehicle preemption would need to be eliminated or severely restricted, and because two of the advisory speed messages would be displayed for such short periods of time (approximately 4 seconds each), it is recommended that a speed funnel system not be installed and tested.

**8.0 Conclusions and Recommendations**

This project has demonstrated a truck priority system can be designed, constructed, and implemented at a relatively low cost. The cost of construction is essentially the cost of installing an additional two loops per approach lane, connecting them to the controller cabinet, providing detector amplifiers for the additional loops, and making minor modifications in the controller cabinet wiring. For the project intersection at the intersection of TH 169 and Laredo Street in Belle Plaine, Minnesota, eight additional loops were installed (two in each lane, two lanes per approach, two approaches on TH 169), and the total installation cost for the truck detection system was less than $20,000 (in 2003).

The truck detection system is effective in accurately detecting heavy commercial vehicles (tractor-trailers) as they pass over the loops in the detection system. Some false calls (false in the sense that they were not heavy commercial vehicles) from passenger vehicles pulling trailers are
received by the controller, but the frequency of these false calls is relatively low.

As described in Section 6.0 and as shown below in Table 2, the results of the truck priority system benefits analysis were mixed. The truck priority system exhibits the ability to reduce the probability that any given truck will be forced to stop at the traffic signal. It also reduces the probability that the front vehicle in a queue when the signal changes to green will be a truck. On the other hand, the truck priority system, by virtue of providing extended green time for the mainline direction, also results in longer green times for the other traffic movements at the intersection because more non-mainline vehicles are stopped during the longer mainline green times. The resulting longer cycle lengths result in slightly increased delays to all vehicles, including trucks. Although fewer trucks are stopped, those trucks that are stopped remain stopped for longer periods of time.

**Table 2**

**Summary of Truck Priority System Analysis**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduces the number of trucks that must stop for the signal.</td>
<td>For each truck that is forced to stop, the average amount of time stopped increases.</td>
</tr>
<tr>
<td>Extends the green time for some trucks that normally would have to stop.</td>
<td>Slightly increases average delays to all vehicles (stopped or not) including trucks.</td>
</tr>
<tr>
<td>Reduces the likelihood that the vehicle at the front of the queue is a truck – especially in the right lane, which is the lane most used by truck traffic.</td>
<td>Traffic signal green time for the cross street – and, therefore, red time for the mainline – also increases.</td>
</tr>
<tr>
<td>Traffic on crossing street is not significantly affected – either positively or negatively.</td>
<td></td>
</tr>
</tbody>
</table>
of the speed funnel system with fewer potential technical and operational problems and with lower exposure to liability from crashes.
Appendix A

E-Mail Message sent to the Departments of Transportation
State DOT’s 49 U.S. states (excluding Minnesota) were surveyed for any work or research in which they had been involved or of which they were aware that provided priority for heavy commercial vehicles. Following is the e-mail message sent.

“If you are not the individual to whom this request should have been sent, please either forward this request to the appropriate individual at our agency or provide me with information so that I can contact that individual directly. Thank you.

“The Minnesota Department of Transportation (Mn/DOT) has hired Short Elliott Hendrickson (SEH) Inc. to develop a system to provide priority for heavy commercial vehicles at isolated signalized intersections on state routes. You are being contacted because, as part of that project, SEH is required to survey other state transportation agencies concerning methods those agencies may have researched or implemented, whether successful or not, in reducing delays and stops to trucks and/or to vehicle affected by truck operations.

“Therefore, I am requesting that you take a few moments of your time to provide a brief description of any and all such projects in which you agency has been involved. Also, if you are aware of any research which has been conducted on this topic, whether published or not, please mention that in your response. If available, please also provide contact information for individuals who have been involved in these projects or research activities.

“PLEASE RESPOND whether your agency has been involved in any such project or not, or whether you are aware of related research or not. A response indicating no knowledge of related projects or research is of more value to SEH and Mn/DOT’s current project than no response at all.

“If you so request in your response, SEH will send a summary of project findings to you when the project is complete.

“Respond via e-mail to: RPlum@sehinc.com

“or respond via regular mail to:

    Roger Plum, PE, PTOE
    3535 Vadnais Center Drive
    St. Paul, MN 55110-5196

“or contact Roger Plum, SEH’s Project Manager, at (612) 758-6761.

“Thank you for your time and cooperation.”
Appendix B

E-Mail Message sent via the Institute of Transportation Engineers Traffic Engineering Council
Text of E-Mail Message sent via the Institute of Transportation Engineers Traffic Engineering Council List-Serve to its Members

The ITE Traffic Engineering Council list-serve was also surveyed for information pertaining to truck priority. The message posted on September 2, 2003, was:

“We are in the process of developing for the Minnesota Department of Transportation a method of providing priority for heavy commercial vehicles (tractor/semi-trailer combinations) at isolated signalized intersections. As part of that effort, we are interested in learning of any other priority treatment systems for these types of vehicles which have been implemented by other agencies – whether successful or not – or for which research has been conducted – whether published or not.

“All U.S. state departments of transportation have been contacted within the last two months, but not all have responded. Therefore, receiving any additional information (descriptions of and/or contact information for implementation projects or research) which you can provide would be greatly appreciated.

“Thank you in advance for your assistance. If you have already responded on behalf of a state DOT, no additional response is necessary, and thank you again.

Roger A. Plum, PE, PTOE
Senior Transportation Engineer
612.758.6761 SEH – Minneapolis, or
651.765.2966 SEH – St. Paul”
Appendix C

Project CD Contents
Following is a description of information contained on the CD-ROM accompanying this report.

1. The final report (this document)
2. Documentation concerning previous research and implementation
   b. “Reducing Truck Stops at High-Speed Isolated Traffic Signals” (Report 1439-8), September 2000
3. CORSIM Runs
4. Functional Requirement Specification
5. Technical Requirement Specification
6. Operational Requirement Specification
7. Maintenance Requirement Specification
8. Stop and Delay Study Results and Plots