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16. Abstract

Border areas have seen a steady increase of truck traffic. This increase in truck traffic causes an increase in pavement deterioration, which is amplified by trucks stopping at traffic signals. Reducing the number of stops made by trucks at high-speed rural intersections can significantly reduce delay and pavement damage. This project developed a truck priority logic and implemented it at an intersection in Sullivan City, Texas, to reduce truck stops. The project used a TCC 540 classifier and an industrial PC to implement this logic. The logic was developed with adequate safety features. Implementation of the truck priority logic indicated that there was a reduction in truck stops at the intersection.

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REDUCING TRUCK STOPS AT HIGH-SPEED ISOLATED TRAFFIC SIGNALS

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REDUCING TRUCK STOPS AT HIGH-SPEED ISOLATED TRAFFIC SIGNALS

1.0 Objective

The work done in this project is a refinement of the work done and documented in Research Project 7-2972, which was completed in 1997. The objective of this project (0-1439) was to develop dilemma zone treatments for truck traffic at high-speed rural intersections using loop detectors rather than the more expensive detection system used in Project 7-2972. Project 0-1439 used loop detectors and developed the methodology to identify trucks. Appropriate treatment of trucks would minimize truck stops and traffic delay while improving safety, reducing pavement wear, and decreasing traffic delay. This system had to be reasonably accurate, easy to operate, and cost effective.

2.0 Description

The intersection of US 83 and FM 886 in Sullivan City, Texas, was selected as a site to implement and evaluate the truck detection system in the earlier project (Project 7-2972). The major arterial (US 83) is an east-west arterial. Researchers decided to instrument only the eastbound approach to test the concept. The objective of the original project was to test and evaluate a number of different sensors. These sensors included the Schwartz Autosense II (AS II) by Schwartz Electro-Optics, Inc. (SEO), which is an active infrared unit; Smart Sonic by International Road Dynamics Inc. (IRD), which is a passive acoustic unit; and a Traffic Counter/Classifier (TCC) 540 classifier by IRD, which is an inductive loop classifier. The AS II unit was more accurate and more expensive than the Smart Sonic Unit for vehicle and speed classification. However, the TCC 540 by IRD was found to be most suitable due to its accuracy and its reasonable cost (*1*).

The TCC classifier requires a pair of loops in each lane to identify trucks and determine their individual speeds. Figure 1 illustrates the loops installed at the site. These loops were installed at a distance of 550 feet upstream from the intersection. This distance was based on the approach speed and loops positioned to provide the appropriate dilemma zone treatment. Literature reviews (*2*) showed that large trucks could stop from 60 mph in approximately 300 feet. However, Texas Transportation Institute's (TTI) field data for speeds of 55 mph do not indicate that truck drivers are willing to accept this high deceleration rate. Hence, the research team estimated the braking distance at approximately 400 feet. Adding driver reaction time of 1.0 second to an appropriate braking distance of 400 feet requires that the front of a truck be no closer than 480 feet to the stop bar when the yellow indication comes on. Determining the location of a detection system still requires adding the length of the design vehicle and an additional distance for the detector's processing time. Assuming 65 feet and 0.2 seconds for vehicle length and processor time, respectively, detectors should be placed at approximately 560 feet for a design speed of 55 mph. Texas Department of Transportation (TxDOT) staff installed two pairs of loops spaced at 18 feet in each of the two lanes. The lead from each of these loops was brought back to the classifier.

The truck detection system consists of the TCC classifier, an industrial Pentium personal computer (PC) with software, and a digital input/output (I/O) board to communicate with the signal controller. The digital I/O board facilitates two-way communication between the PC and the signal controller cabinet. The PC, TCC classifier, and the digital board are placed in a cabinet behind the signal controller cabinet. Figure 2 illustrates the two cabinets at the intersection.

Figure 1. Loops Placed on the Eastbound Approach

Figure 2. Cabinets Located Back to Back at the Intersection

3.0 Methodology

The methodology for operating the system is very simple, as illustrated by Figure 3. The classifier obtains the actuations from the two pairs of loops on the eastbound approach and determines the vehicle class and speed. The vehicle classification and the speed of the vehicle are communicated in real time to the algorithm running on the field computer. The algorithm also obtains the signal status information from the back panel of the signal controller cabinet via the digital I/O board.

Based on the signal status and the speed of the truck, the program determines if a hold call needs to be placed. If a truck arrives during the red indication, no hold call will be placed. A call for hold will be placed if a truck arrives during the green indication. The call for hold will be placed at the back panel of the signal controller via the digital I/O board. The duration of hold will depend on the truck speed. Figure 4 shows the hold requirements based on the detected truck speed. This graph uses an assumption that a 30-foot truck enters the intersection with 2 seconds remaining in the yellow duration.

The algorithm and its user interface used to determine when to place a hold and its duration are very user-friendly. The operator can define different hold durations for five speed categories as well as define the speed thresholds for each speed category.

The algorithm includes two safety features. One is a user-defined upper limit of the phase hold duration in case of consecutive truck actuations. This safety measure prevents excessively long hold durations and long arterial greens. A second safety feature uses a timer relay of 2 minutes to prevent excessively long holds in case of a malfunction. This timer relay was specifically acquired and incorporated as an independent monitor of the system performance with respect to the hold call.

4.0 Deployment

After extensive testing in College Station, Texas, TTI deployed the system at the intersection in Sullivan City with assistance from TxDOT personnel. TTI and TxDOT personnel calibrated parameters of the phase hold based on field observations. Table 1 illustrates the specified hold duration for each speed category in use in Sullivan City.

5.0 Evaluation

TTI installed the system at the end of May 1999. Subsequent to its installation TTI monitored the system for three weeks. TTI researchers have the capability to monitor the system remotely from College Station. It is possible to upload the daily log file via the telephone lines from the PC in the field to the laboratory in College Station using a software program called PCAnywhere. The log file documents the activity of the classifier and the PC for the entire day. Figure 5 illustrates a summary of the log file. It is also possible to download and install upgrades to the software in the field PC from the laboratory. Researchers made minor adjustments to the software to enhance its usability.

After three weeks, TxDOT personnel disabled the functionality of the system to hold the phase in the traffic signal controller by disconnecting the wire in the back panel but kept the system running to facilitate collecting the “before” data. Hence, it was possible to collect all the data that the evaluation would require. After collecting the “before” data for about four weeks, TxDOT personnel enabled the hold functionality of the system to the signal controller cabinet and activated the system to collect the “after” data.

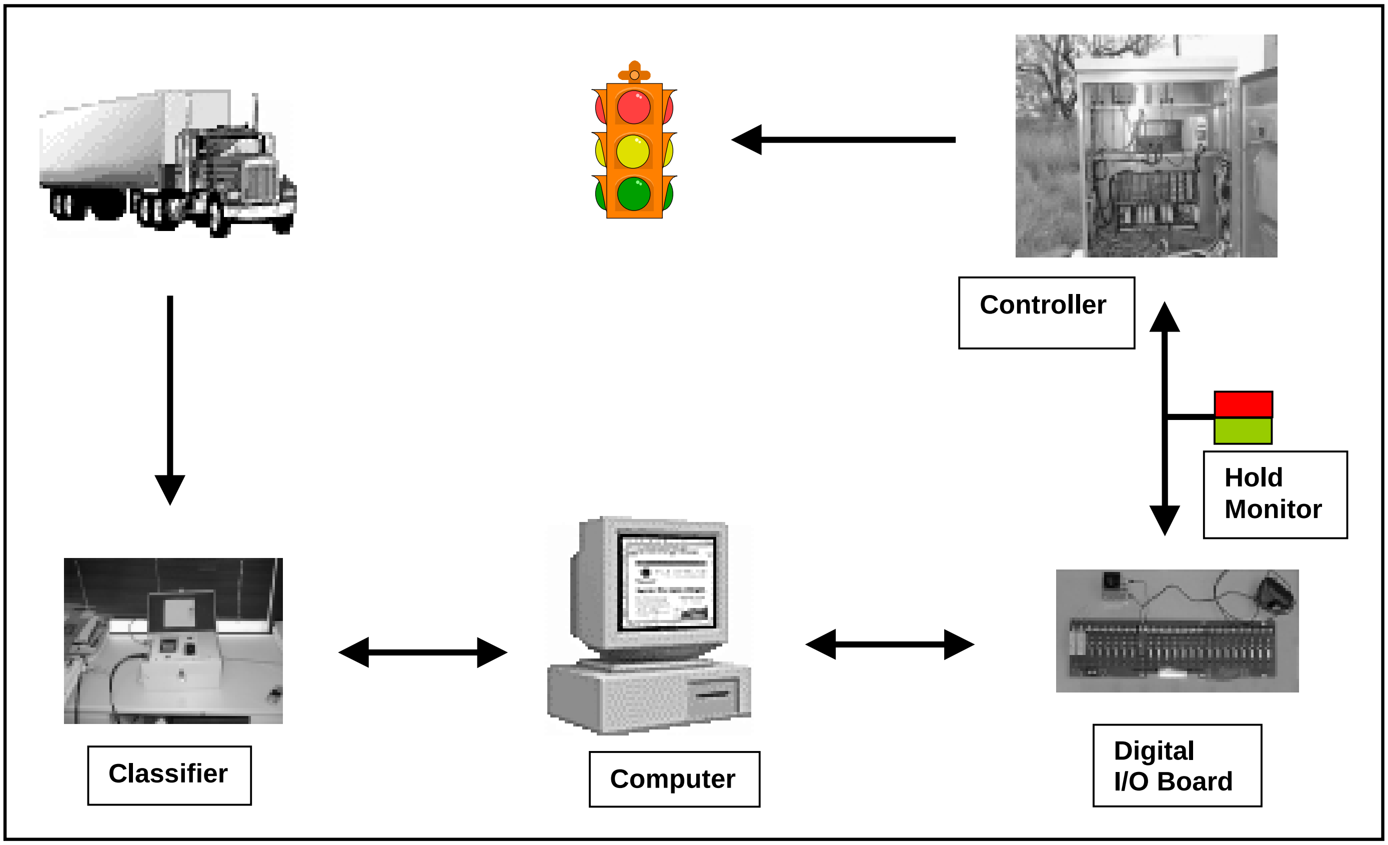

Figure 3. Methodology for Operating the Truck Priority System

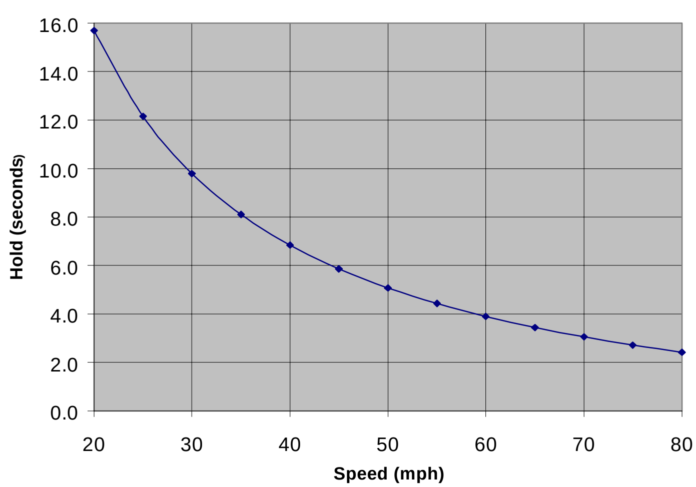

Figure 4. Hold Requirements for Different Speeds

Table 1. Hold Durations Specified for Each Speed Category (Range)

Speed Range	Hold Duration
Under 35 mph	None
35 – 50 mph	8.0 seconds
50 – 60 mph	5.5 seconds
60 – 70 mph	4.0 seconds
Over 70 mph	3.5 seconds

Truck Statistics for PHASE 6

Total Number of Trucks Detected: 515

Number of trucks required phase hold of 8.00 seconds (35 < Truck Speed <= 50) = 373
Number of trucks required phase hold of 5.50 seconds (50 < Truck Speed <= 60) = 54
Number of trucks required phase hold of 4.00 seconds (60 < Truck Speed <= 70) = 3
Number of trucks required phase hold of 3.50 seconds (Truck Speed > 70) = 0
Number of trucks with speed less than minimum speed limit 35 mph = 85

Total Number of Non-Trucks Detected = 7179

Number of Non-Trucks detected on Green = 4456
Number of Non-Trucks detected on Red = 2723

Total Number of Trucks Required Phase Hold = 430

Number of consecutive trucks detected = 22
Number of phase hold requests on Green = 271
Number of phase hold requests on Red = 137

07:02:1999 00:00:00:000 :: End Of Day

End Of File: 711999.Tcc

Figure 5. Summary of the Log File Created at the End of Each Day

5.1 Anticipated Benefits

This system is expected to benefit the trucks arriving faster than 35 mph on the eastbound approach of the intersection. The system will initiate the "hold phase" only for trucks arriving at certain portions in the signal cycle. The system will not provide any benefit to the trucks detected during the red phase. For trucks arriving during the green phase, the system could place a hold and benefit the truck that otherwise may have had to stop because of phase termination due to a gap in the traffic. For trucks arriving at the very end of the green phase, the phase hold could benefit the truck that otherwise may have had to stop because of a "max out" phase termination. After discussions with TxDOT, TTI researchers listed potential benefits of the truck priority system. While attempts will be made to quantify these benefits, some factors are difficult to assess at the present time. The anticipated benefits include:

- **Reduced pavement wear**
  Increased truck traffic causes increased pavement deterioration and deformation. This damage is greater when these trucks apply the brakes and then start again at signalized intersections.

  Based on the opinion of a pavement expert at TTI, the quantification of the benefits is a very complex and difficult task. However, the expert's opinion was that "any" reduction in truck stops would reduce pavement damage. The damage to the pavement and the sub-surface depends on the speed and weight of the trucks. Trucks moving at slower speeds cause more damage to the pavement and sub-surface. Thus, it is essential to minimize truck stops to reduce pavement wear and tear.

- **Reduced delay to trucks**
  Minimizing truck stops by inference reduces delay experienced by trucks. Research indicates that each stop by a truck causes a delay of 2 minutes for just deceleration and acceleration (*3*). This delay does not include the delay experienced while stopped at the signal. The cost of delay has been estimated at $34/hour (*4*).

- **Reduced traffic delay due to fewer truck stops**
  The *Highway Capacity Manual* (*5*) has incorporated a heavy vehicle adjustment factor in the estimation of saturation flow rates for estimating delay at signalized intersections. This adjustment factor ranges from 0.946 to 0.909 for percentage truck traffic ranging from 6 to 10 percent. This factor implies a direct effect on the capacity of the approach at the intersection and, in turn, on the overall operation of the intersection.

- **Reduced fuel consumption and emissions**
  Stopping and starting of trucks results in an increase of fuel consumption. A review of literature indicated that each truck stop results in the use of an additional third of a gallon of fuel (*4*). Over a long period, reducing stops can amount to a large saving in fuel consumption. This decrease in fuel consumption in turn results in a reduction in vehicle emissions.

- **More cars cleared during the hold duration**
  The hold feature allows trucks to safely clear the intersection without stopping. At the same time, there may be other vehicles (non-trucks) that can utilize the hold and clear the intersection during the same hold. Thus, the hold is benefiting other vehicles. This benefit can be observed in any change in the percentage of non-trucks arriving in green. Any increase in delay to the minor street is offset by the main-street green extensions.

- **Reduced brake/tire wear**
  While no documentation could be found about the brake and tire wear of trucks due to stopping, the research team inferred that a reduction in stops would cause a reduction in wear and tear of brakes and tires of trucks.

- **Clearing more trucks on the westbound (WB) approach**
  The eastbound approach is instrumented. A hold call for the eastbound approach also holds the westbound approach, which allows some trucks and non-trucks to clear the intersection that otherwise may have stopped. Since the westbound approach is not instrumented, it will not be possible to quantify any such benefits.

5.2 Data Analysis

The data collected were analyzed to evaluate the impacts of using the system to minimize stops of trucks. Preliminary analysis of the data revealed some trends that can be attributed to a weekly routine. Hence, the research team decided to analyze the data on a weekly basis. It was decided to collect about three weeks of data in the "before" and "after" study and compare the effectiveness of the system. The collection of "before" data began June 20, 1999, and ended July 24, 1999. TTI collected two extra weeks of data, as some data were lost when the system was down for a day each during the second and fourth weeks.

The "after" data collection began on July 25, 1999. However, the data collection effort encountered numerous technical difficulties at the intersection. These difficulties included construction at the site, a malfunctioning detector, and the controller going into flash mode. Hence, it took 10 weeks of data collection to obtain three weeks of acceptable data. The "after" data were collected until October 2, 1999. Even in these days for a variety of reasons, data from a few days were atypical. Hence for those days, typical data from some of the other weeks were transposed and a typical week of data was constructed. Table 2 illustrates the dates of the data in the "before" and "after" study to evaluate the system.

Table 2. Dates of Data Collection

Before Data			After Data		
Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
June 20	July 4	July 18	August 22	September 19	September 26
June 21	July 12	July 19	August 23	September 20	September 27
June 22	July 6	July 20	September 14	September 21	September 28
June 23	July 7	July 21	September 15	September 22	September 29
June 24	July 8	July 22	September 16	September 23	September 30
June 25	July 9	July 23	September 17	September 24	October 1
June 26	July 10	July 24	September 18	September 25	September 4

In the "before" study, data from July 5 were replaced with data from another Monday, July 12, because the traffic pattern on July 5 was not typical due to the July 4 weekend. In the "after" study, data from September 12 and 13 were replaced with data from August 22 and 23 (another Sunday and Monday) because the system was down during those days. Similarly, the controller went into flash on October 2 and the data for that Saturday had to be replaced with data from another Saturday (September 4).

5.3 Volumes

The first objective was to ensure that the "before" and "after" data were collected at similar volume levels. Figure 6 illustrates the comparison of the traffic and truck volumes during the first week of comparison. The figure shows that the traffic patterns are reasonably constant during the week at about 7000 to 8000 vehicles per day. However, the truck volumes clearly drop from about 550 trucks during the weekdays to about 200 during the weekends. Also, there seemed to be more trucks on three of the days in the week in the "after" study. In Week 1, there was an increase of 13 percent in the number of trucks while the traffic levels increased by about 1 percent. This increase in truck traffic may not affect the evaluation process.

After establishing the similarity in the volume levels, the data were analyzed to study the impacts of the system on the traffic operations at the intersection. The log files record the onset and the termination of green, the arrival of trucks and non-trucks, their speeds, and the resultant call of a phase hold if warranted. Thus, the log file has a complete log of the activities of the classifier as well as the PC.

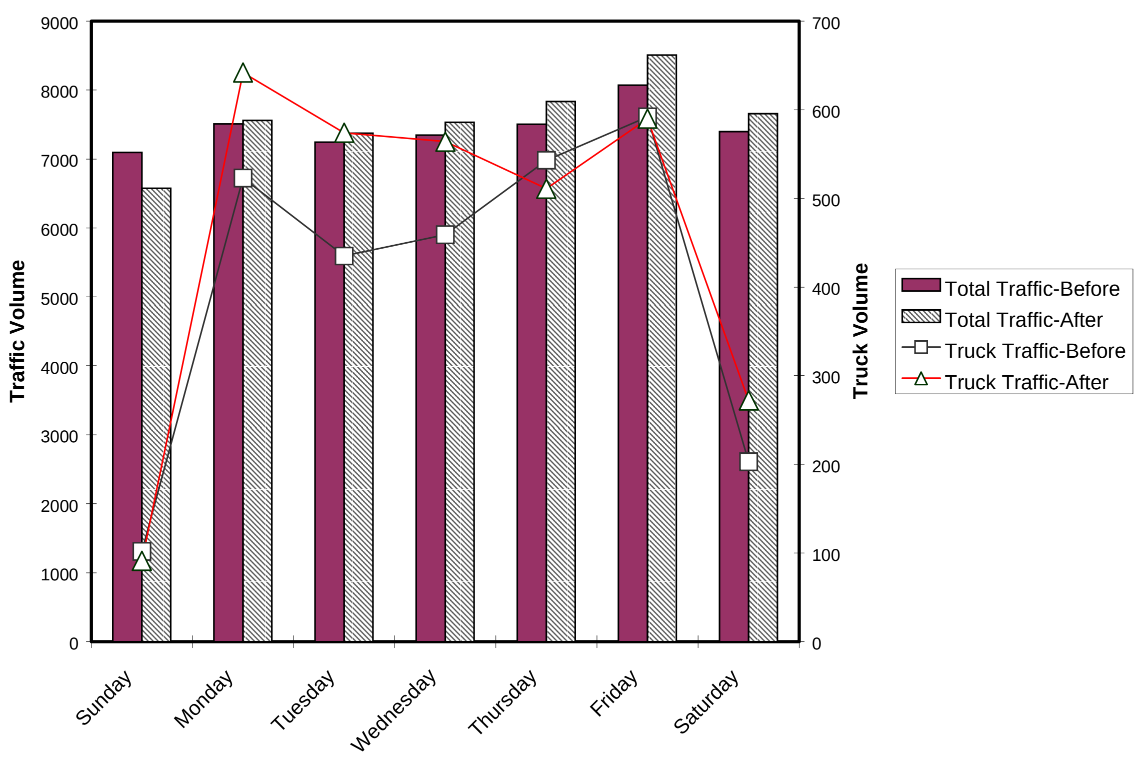

Figure 6. Traffic and Truck Patterns during Week 1

5.4 Phase Termination during Phase Hold in "Before" Study

As mentioned earlier, during the "before" study, the connection to the phase hold was not made with the back panel in the signal controller cabinet. Hence, when a call is placed on one of the conflicting phases, the main street phase can terminate before the phase hold call expires. From the log files, the research team measured "numbers of phase terminations during the phase hold". This measurement is the number of times the truck could have benefited from a call for a hold. This number is definitely the minimum number of trucks that could have benefited if the phase hold was active. While such cases will be seen in the "before" study, the "after" study should not have such cases, as the phase cannot end in the middle of the phase hold. The analysis also looked at the log files from the "after" study and discovered a few cases where the phase terminated during the phase hold. Further analysis found an explanation for such cases. In all these cases, the truck arrived a fraction of a second before the phase was terminated. The phase termination was then attributed to the processing time required to process the truck call for a phase hold. Thus, such truck arrivals can be assigned to an arrival on the red. Table 3 summarizes the percentage of phase terminations in the middle of the phase hold for each day of the "before" and the "after" study.

Table 3. Percentage of Phase Termination in the Middle of the Phase Holds

	Week 1		Week 2		Week 3	
	Before	After	Before	After	Before	After
Sunday	4.9%	0.0%	7.8%	1.1%	2.2%	0.0%
Monday	4.4%	0.3%	2.1%	0.3%	4.2%	0.2%
Tuesday	3.4%	0.2%	3.8%	0.2%	3.1%	0.4%
Wednesday	6.5%	0.0%	3.9%	0.4%	3.5%	0.0%
Thursday	5.3%	0.4%	6.1%	0.0%	5.0%	0.2%
Friday	4.4%	0.0%	4.7%	0.2%	3.8%	0.2%
Saturday	4.4%	0.4%	3.2%	0.0%		
Average	4.8%	0.2%	4.5%	0.3%	3.6%	0.2%

Table 3 indicates that, on average, about 4 percent of trucks could have benefited from a phase hold. While 4 percent may appear to be a very small benefit, the system can provide a priority only to the trucks arriving on the green indication. Data collected showed that an average of 55 percent of the trucks arrived on the green indication of the phase. This 4 percent is also the number of trucks arriving at the "end of the green" that definitely could have used a hold. There can be trucks requiring a hold that arrive in the middle of the green too since this intersection is operating in an isolated manner and the phase can terminate at any time after the minimum green. For an average weekly truck volume of about 2500, 100 trucks could have benefited due to a phase hold, which equates to a reduction of at least 5200 truck stops per year.

Based on these findings regarding phase holds, one can quantify the benefits of reduced truck delay and reduced fuel consumption due to a reduction in truck stops. A reduction of 5200 truck stops equates to savings of $5,882 based on 173 hours of delay at $34 an hour (*4*). Similarly, a reduction of 5200 stops equates to fuel savings of 1733 gallons which is equivalent to $2,045 at $1.18 per gallon (*4*). Hence, from just two quantifiable benefits, the system will save $7,927 per year. Even though this evaluation does not quantify other benefits associated with it, a favorable benefit-to-cost relationship is anticipated over the life of the system. In fact, the system reaches a break-even point in just under two years. Table 4 shows anticipated components and total cost for a single two-lane approach.

Table 4. Cost of Installing the System for a Single Two-Lane Approach

Component	Cost	Remarks
Loops (4)	$2,000	@ $500 per loop
Conduit and cable	$6,000	@ $10 per foot of conduit/cable
PC	$3,000	
Digital I/O Board	$500	
TCC Classifier	$3,500	
Total	$15,000	

6.0 Technical Challenges

The project faced a number of challenges before TTI researchers could implement the system. The TCC classifier had a problem of automatically shutting off at midnight. To solve this problem, research staff moved the equipment to College Station in February 1999. The problem was in the classifier and not any other software or hardware associated with the project. The electrically read only memory (EPROM) in the classifier was upgraded to eliminate the problem.

The software developed for operating the system during the 7-2972 project was not very user friendly. TTI programmers modified the software and made it very easy to operate. This allowed for easier configuration of the system based on user preferences. The output was modified to allow better understanding of the system and to facilitate easier evaluation.

7.0 Conclusions

The system implemented at the site in Sullivan City functioned satisfactorily. The data suggest that the system is effective at reducing truck stops and will pay for itself in less than two years with the current configuration. The system was built by integrating off-the-shelf components to demonstrate it as a proof of concept. These components can be integrated into a signal controller unit to build a more robust and cost effective system. The draft specifications for the system are included in the Appendix.

8.0 Recommendations

Although the system is operating satisfactorily in the field, it does not appear advisable to adopt this scheme for statewide practice at this time. The current detector configuration for truck priority has loops placed and operated independent of the loops placed for normal operations. This dual loop placement configuration can be expensive and redundant. TxDOT is sponsoring another project (0-4022) that can develop a detector configuration that will combine the functionality of conventional detection as well as the requirements for a truck priority system. It is recommended that future implementation be postponed until recommendations are received from Project 0-4022.

9.0 References

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APPENDIX

Draft Specification

Revision to Traffic Controller Specification for Selected Isolated High-Speed Rural Signals

These specifications are intended to allow a traffic signal controller to identify a truck on a high-speed approach, determine the truck speed, and hold the green for that approach so that the truck can clear the intersection without stopping. These specifications include loop inputs, a Classification Module to classify the vehicle and obtain the speed, a Hold Module with a user interface to allow the user to input a hold duration for the applicable truck speed, and some safety features.

Loop Inputs:

1. The controller should be able to accept inputs from a pair of loops in each lane from each approach (phase). These loop inputs can be called vehicle classification loops.

Classification Module:

1. The Classification Module may either be incorporated within the traffic signal controller unit or be a separate unit in the controller cabinet and should be able to communicate to the Hold Module in the signal controller unit.
2. The module should be able to receive the inputs from each of the pairs of classification loops.
3. The module should identify any trucks passing over the classification loops. This classification can be based on the length of the vehicle.
4. The module should also determine the speed of the vehicles passing over the classification loops.

Hold Module:

1. The Hold Module should be able to receive the communication from the Classification Module and the signal status information in the signal controller.
2. The communication from the Classification Module includes the information about vehicle classification as a truck as well as the speeds of all the vehicles.
3. The Hold Module should have at least 5 (five) categories for hold durations based on the speeds of the vehicles in miles per hour. Each of these categories will have a lower speed limit and an upper speed limit with a hold duration in seconds for each speed category.
4. Based on the speed of the truck, the Hold Module should select the hold duration for that specific truck from the speed category table and generate a hold call. The module should then determine if the phase the truck has been detected on is green. If the signal status of the particular phase is green, this hold call with the specific hold duration should be applied to that phase. If the phase status is not green, the call for a hold by truck should be ignored.
5. If a second hold call is generated before the release of the first hold, the appropriate hold call should be applied such that the hold call for both the trucks is satisfied without any excessive hold duration. For example, consider a case where Truck 1 requires a hold of 7 seconds and Truck 2, requiring a hold of 6 seconds, is detected 2 seconds after Truck 1 is detected. The Hold Module should NOT place two hold calls of 7 seconds (Truck 1) and 6 seconds (Truck 2) for a total of 13 seconds of hold. The hold duration should be computed as follows:

Case 1:

Truck 1 arrived at T1	=	0 seconds
Truck 1 hold (Hold 1)	=	7 seconds
Truck 2 arrived at T2	=	2 seconds
Truck 2 hold (Hold 2)	=	6 seconds

Elapsed time in Hold 1 when Truck 2 arrives	=	Hold 1 – T2
	=	7 – 2
	=	5 seconds

Since Hold 2 (6 seconds) > 5 seconds, apply Hold 2 to the signal controller.

This will ensure that Truck 1 will get adequate hold to clear the intersection and Truck 2 will get its required hold to clear the intersection

The following example shows another case of determining the hold duration when a second hold call is generated before the release of the first hold. In this case, the second truck arriving is a much faster truck and requires only 4 seconds of hold.

Case 2:

Truck 1 arrived at T1	=	0 seconds
Truck 1 hold (Hold 1)	=	7 seconds
Truck 2 arrived at T2	=	2 seconds
Truck 2 hold (Hold 2)	=	4 seconds

Elapsed time in Hold 1 when Truck 2 arrives	=	Hold 1 – T2
	=	7 – 2
	=	5 seconds

Since Hold 2 (4 seconds) < 5 seconds, continue applying Hold 1 to the signal controller.

This will ensure that Truck 1 will get its adequate hold to clear the intersection and Truck 2's hold requirement will be met by the available hold duration in Hold 1.

Such a logic will ensure that the hold calls are applied smartly without wasting any time.

Safety Features:

1. There will be two safety features in the system.
2. The Hold Module user interface will allow the user to input an upper limit on the hold duration in case of consecutive truck arrivals. This feature will prevent excessively long arterial greens and avoid excessive delays to the cross street traffic. When the hold duration reaches the user defined upper limit, the hold call is released and the controller resumes normal operations. Subsequent hold calls are treated normally.
3. There will be a Hold Monitor that will be external to the system. The function of the Hold Monitor would be to continuously monitor the holds placed by the Hold Module. This monitor will ensure that if the module is placing a continuous hold

call to the signal controller (a user specified value) due to a malfunction in the Hold Module, the Hold Monitor would terminate the hold call. The signal controller will then resume normal operations and subsequent hold calls will again be treated normally.