TP 13400E

Automated Downgrade Truck Speed Advisory System

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BRITISH COLUMBIA

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by

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16. Abstract

The purpose of the project was to determine the technical feasibility and effectiveness of a downhill truck speed advisory system (DTSAS) in a slow speed application. These systems use weigh-in-motion (WIM) technology to weigh and classify the trucks and a variable message sign (VMS) to inform drivers of an advisory descent speed prior to a long steep grade. At project initiation only one DTSAS was already installed in Colorado. Three roll-over warning systems using the same technology had been installed in the Washington, D.C., area. They were installed on high-speed highway facilities (speeds greater than 70 km/h [~50 mph]). Early results from these U.S. locations indicated that the system is effective.

The B.C. installation was unique for a number of reasons. The DTSAS was located in an area of severe winter conditions. The site was on an 8% downgrade with a posted speed limit of 50 km/h and a truck advisory speed of 20 km/h. Also, a secondary system, known as the speed notification system (SNS), was installed downstream. It provided driver feedback by measuring and displaying truck speed. This second system was located approximately 1 km in advance of a truck runaway lane. At this point the driver would know the advised truck speed and the measured truck speed and would be able to make an assessment and decide whether or not to choose the truck runaway lane.

Tests indicated that the WIM performance did not meet the specification. Since the technology had been successfully used in previous U.S. installations, site characteristics, individually or together, may well have contributed to the unsatisfactory result. In the manufacturer's final investigation, it was recommended that to achieve the original specification with piezo-electric sensors, truck speeds over the sensors would need to be greater than 40 km/h, and the temperature above 5^{o}C. Hence, it was decided to display steep grade information on the VMS in lieu of truck advisory speeds. The SNS continues to display measured truck speeds.

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16. Résumé

L'objectif de ce projet était de déterminer la faisabilité technique et l'efficacité d'une application faible vitesse d'un système de détermination de la vitesse sûre de poids lourds en descente (DTSAS, pour *Downhill Truck Speed Advisory System*). Ces systèmes utilisent la technologie de pesage dynamique pour peser et classer les poids lourds, et un panneau à message variable pour informer les camionneurs, à l'approche d'une longue pente raide, de la vitesse de descente recommandée. Au moment d'entreprendre le projet, un seul système de détermination de la vitesse sûre de poids lourds en descente était déjà en service, au Colorado. Trois systèmes d'avertissement dynamique étaient installés dans la région de Washington, D.C., sur des autoroutes à grande vitesse (dépassant les 70 km/h [50 mi/h]). Les premiers résultats provenant de ces sites indiquaient l'efficacité du système.

L'installation du système en Colombie-Britannique était unique pour un certain nombre de raisons. Le système était installé dans une région soumise à des conditions hivernales rigoureuses. Le site se trouvait dans une pente de 8 p. cent d'inclinaison où la limite de vitesse était de 50 km/h et la vitesse recommandée pour les poids lourds était de 20 km/h. Un système secondaire, appelé système d'indication de la vitesse (SNS, pour *Speed Notification System*), était aussi installé en aval du DTSAS, mesurant et affichant, à l'intention du camionneur, la vitesse du poids lourd. Ce second système était situé environ 1 km avant une voie de détresse pour poids lourds. Rendu à ce point de la descente, le camionneur connaissait la vitesse recommandée et la vitesse réelle de son poids lourd, pouvait évaluer la situation et choisir d'emprunter ou non la voie de détresse.

Les essais ont montré que la performance du système de pesage dynamique n'a pas répondu aux exigences fixées. Puisque la technologie a déjà été utilisée avec succès sur les sites américains, certaines ou l'ensemble des caractéristiques du site canadien pourraient avoir contribué au mauvais fonctionnement du système. Dans l'étude finale du fabricant, il a été établi que, pour respecter les spécifications initiales au moyen des capteurs piézo-électriques, la vitesse des poids lourds passant au-dessus des capteurs devait dépasser 40 km/h et la température, 5 °C. Il a donc été décidé d'afficher un avertissement de pente raide sur le panneau à message variable au lieu des vitesses recommandées pour les poids lourds. Le système d'indication de la vitesse indique toujours la vitesse mesurée des poids lourds.

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EXECUTIVE SUMMARY

The purpose of the project was to determine the technical feasibility and effectiveness of a downhill truck speed advisory system (DTSAS) in a slow speed application. Previous research had indicated that automated truck advisory systems could reduce specific truck accidents. The automated systems immediately provide the driver with truck specific advisory information, whereas static signage is more general. These systems use weigh-in-motion (WIM) technology to weigh and classify the trucks and a variable message sign (VMS) to inform drivers of an advisory descent speed prior to a long steep grade. At project initiation only one DTSAS was already installed, in Colorado. Roll-over warning systems using the same technology had been installed in Virginia and Maryland. They were installed on high-speed highway facilities (speeds greater than 70 km/h [~50 mph]). Early results from these U.S. locations indicated that the system is effective.

Through analysis of truck accident statistics, the B.C. Ministry of Transportation and Highways (MoTH) Highway Safety Section determined that a positive benefit-cost ratio would be achieved by installing a DTSAS at the Warfield Hill on Route 3B between Rossland and Trail, B.C. This hill is approximately 10 km long with grades reaching 10%. MoTH contracted International Road Dynamics Inc. (IRD), the Canadian manufacturer, to install and commission the system.

The site and installation have several unique characteristics. Typical WIM installations are on a flat roadway. Due to geographic restrictions, it was necessary to install the WIM on an 8% downgrade. This was a relatively slow speed application of WIM in that, although the posted speed limit was 50 km/h, a static truck speed advisory sign called for 20 km/h. The region is also subject to severe winter conditions.

A secondary system known as the speed notification system (SNS) was installed downstream to measure and display truck speed only, in order to provide feedback to the driver. This second system was located approximately 1 km in advance of a truck runaway lane. At this point the driver would know both the advised truck speed and the measured truck speed and hence would be able to make an assessment and decide whether or not to choose the truck runaway lane.

The project was initiated in fall 1996 and all components were installed in spring 1997. System calibration by IRD and MoTH acceptance testing were carried out

in the summer and fall of 1997. A sampling of trucks from the general traffic stream was used for acceptance testing. Trucks were weighed at the Rossland weigh scale and that weight was compared to the WIM results. It was found that performance was acceptable during warm summer months but not in colder weather. Since this technology had been successfully used in previous U.S. installations, it is possible to conclude the characteristics of this particular site, either individually or together, result in the measured performance not meeting the specification. The key characteristics of the site are that it is on an 8% grade, loaded trucks descend the grade at or close to the advisory speed of 20 km/h, and the site experiences a very wide range of temperatures. Unfortunately, none of these factors can be changed, so it is not possible to determine the degree to which any single factor contributes to performance degradation. Twenty kilometres/hour is near the low speed threshold for Type II WIM as defined by the American Standard Test Methods (ASTM) specification. As well, the 8% grade exceeds the maximum allowable grade of 2% specified by ASTM. These factors, in conjunction with reduced performance of the piezo-electric sensors at cold temperatures (near freezing), cumulatively affect system performance. In its last investigation of the problem, IRD recommended that to achieve the original specification with piezo-electric sensors, truck speeds over the sensors would need to be greater than 40 km/h and the temperature above 5^{o}C.

Faced with these difficulties in meeting the specification with the piezo-electric sensors, MoTH decided to close the project. The DTSAS function of providing truck specific advisory speeds was stopped; however, the VMS sign continues to provide steep grade information to truck drivers. The SNS continues to measure and display truck speed to truckers in advance of the truck runaway lane.

Truck drivers' reactions to the system were mixed. The Warfield Hill sees a large percentage of repeat drivers every week. A segment of this group felt that, as seasoned drivers continually driving the same route, they did not need this type of system. Others in the group felt that any safety measure was welcome.
A frequently voiced opinion was that the system would most benefit drivers unfamiliar with the hill. This is probably valid and is supported by the fact that during system installation a truck driver unfamiliar with the area experienced smoking brakes and was stopped by the RCMP part way down the hill.

SOMMAIRE

L'objectif de ce projet était de déterminer la faisabilité technique et l'efficacité d'une application faible vitesse d'un système de détermination de la vitesse sûre de poids lourds en descente (DTSAS, pour *Downhill Truck Speed Advisory System*). Des recherches antérieures ont montré que les systèmes d'avertissement informatisés pour poids lourds pouvaient contribuer à réduire certains types d'accidents impliquant ces véhicules. Les systèmes informatisés affichent immédiatement des renseignements destinés aux poids lourds, alors que la signalisation fixe est plus générale. Ces systèmes utilisent la technologie de pesage dynamique pour peser et classer les poids lourds, et un panneau à message variable pour informer les camionneurs, à l'approche d'une longue pente raide, de la vitesse de descente recommandée. Au moment d'entreprendre le projet, un seul système de détermination de la vitesse sûre de poids lourds en descente était déjà en service, au Colorado. Des systèmes d'avertissement dynamique faisant appel à la même technologie étaient installés en Virginie et au Maryland, sur des autoroutes à grande vitesse (dépassant les 70 km/h [50 mi/h]). Les premiers résultats provenant de ces sites indiquaient l'efficacité du système.

Le *B.C. Ministry of Transportation and Highways* (ministère des Transports et de la Voirie de la Colombie-Britannique) a déterminé, par l'analyse des statistiques d'accidents de poids lourds, que l'installation d'un système de détermination de la vitesse sûre de poids lourds en descente, sur la côte Warfield, située sur la route 3B entre Rossland et Trail en Colombie-Britannique, donnerait un rapport avantages-coûts positif. La côte fait environ 10 km de long et comporte des pentes allant jusqu'à 10 p. cent d'inclinaison. Le Ministère a chargé *International Road Dynamics Inc.* (IRD), un fabricant canadien, d'installer le système et de le mettre en service.

Le site et l'installation comportaient plusieurs caractéristiques uniques. Le pesage dynamique se fait habituellement sur une route plane. À cause de la situation géographique, le système de pesage dynamique a dû être installé dans une pente à 8 p. cent d'inclinaison. Il s'agissait là d'une application faible vitesse du pesage dynamique car, même si la limite de vitesse était de 50 km/h, un panneau de signalisation fixe limitait la vitesse à 20 km/h pour les poids lourds. Cette région est également soumise à des conditions hivernales rigoureuses.

Un système secondaire, appelé système d'indication de la vitesse (SNS, pour *Speed Notification System*), était aussi installé en aval, mesurant et affichant

uniquement la vitesse des poids lourds. Ce second système était situé environ 1 km avant une voie de détresse pour poids lourds. Rendu à ce point de la descente, le camionneur connaissait la vitesse recommandée et la vitesse réelle de son poids lourd, pouvait évaluer la situation et choisir d'emprunter ou non la voie de détresse.

Le projet a été entrepris à l'automne 1996 et tous les composants ont été installés au printemps 1997. L'étalonnage du système par IRD et les essais de réception par le ministère des Transports et de la Voirie ont eu lieu à l'été et à l'automne 1997. Un échantillon de poids lourds, prélevé sur le flot général des véhicules, a servi aux essais. Les poids lourds ont été pesés au pont-bascule de Rossland et les résultats ont été comparés avec ceux du pesage dynamique. Il a été remarqué que la performance du système était acceptable durant les mois d'été mais pas lorsque les températures étaient plus froides. Puisque la technologie a déjà été utilisée avec succès sur les sites américains, on peut conclure que certaines ou l'ensemble des caractéristiques du site canadien ont contribué à la piètre performance du système. Les caractéristiques clés du site sont qu'il se trouve dans une pente de 8 p. cent d'inclinaison, que les poids lourds descendent la pente à une vitesse proche de la vitesse recommandée de 20 km/h, et qu'on y enregistre un très large éventail de températures. Malheureusement, aucun de ces facteurs ne peut être modifié et il est donc impossible de déterminer la part de chacun dans la dégradation de la performance du système. Une vitesse de 20 km/h s'approche du seuil de basse vitesse du pesage dynamique de type II, tel qu'il est décrit dans la norme de l'*American Standard Test Methods* (ASTM). De plus, une inclinaison de 8 p. cent dépasse largement la limite d'inclinaison permise spécifiée par l'ASTM, qui est de 2 p. cent. L'ensemble de ces facteurs, conjugués à la baisse de performance des capteurs piézo-électrique à basse température (près du point de congélation), nuisent à la performance du système. Dans sa dernière étude sur le problème, IRD a recommandé que, pour respecter les spécifications initiales au moyen des capteurs piézo-électriques, la vitesse des poids lourds passant au-dessus des capteurs soit supérieure à 40 km/h et la température au-dessus de 5 ^{o}C.

Face aux difficultés à respecter les spécifications initiales en recourant à des capteurs piézo-électriques, le Ministère à décidé d'abandonner le projet. L'affichage de vitesses recommandées par le DTSAS a été interrompu. Cependant, le panneau à message variable continue d'afficher un avertissement de pente raide à l'intention des camionneurs. Le système d'indication de la vitesse continue à mesurer et à donner la vitesse des poids lourds aux camionneurs en amont de la voie de détresse.

Les réactions des camionneurs face au système étaient partagées. Bon nombre de conducteurs passent sur la côte Warfield à plusieurs reprises chaque semaine. Une partie de ces camionneurs ont affirmé qu'en tant que conducteurs expérimentés empruntant continuellement la même route, ils n'avaient pas besoin de ce genre de système. D’autres ont dit que toute mesure de sécurité était la bienvenue. Une des opinions les plus souvent formulées était que les camionneurs peu familiers avec la côte seraient les premiers à bénéficier du système. Cette affirmation est probablement bien fondée et est appuyée par le fait que durant l’installation du système, un camionneur ne connaissant pas la région a fait surchauffer les freins de son véhicule et a dû être arrêté par la GRC à mi-côte.

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1 INTRODUCTION

Accidents involving heavy commercial vehicles are a major concern of highway agencies and other road authorities concerned with road safety. Two specific accident types often associated with severe heavy vehicle accidents are roll-over accidents and runaway accidents. These types of accidents usually involve substantial property damage costs as well as significant human and medical costs arising from deaths and injuries.

Utilizing emerging technology, systems have been developed to combat roll-over and runaway accidents. Automated truck warning systems, which provide vehicle specific information based on road and vehicle characteristics, have the potential to significantly reduce certain types of truck accidents. The vehicle-specific warning message is thought to be considerably more effective and informative than typical static warning signs and thus, offer greater potential for reducing serious roll-over or runaway accidents.

Two systems have been developed to reduce these types of truck accidents: a downgrade warning system and a roll-over warning system. The downgrade warning system uses weigh-in-motion technology (WIM) to weigh and classify the trucks and a variable message sign (VMS) to advise drivers of a recommended safe descent speed prior to descending the long steep grade. The roll-over warning system determines the truck height, truck type, weight, and speed and then warns the drivers if a potential roll-over condition exists. When this project was initiated there had been only one downgrade warning system installed, in Colorado. Roll-over warning systems had been installed in Virginia and Maryland. Early results from these existing U.S. locations indicated that the system is effective [1].

Each system has been installed on a high-speed highway facility (speeds greater than 70km/h ~50 mph). There had not been any installations at slow speed facilities. Nor had there been any installations in Canada. While both systems are potentially applicable to B.C., it was decided to implement a downgrade warning system first, in an effort to address specific problems at one location, the Warfield Hill on Route 3B between Rossland and Trail, B.C.

This project was important from the operational and technical perspectives since it was applying a downgrade warning system in a slow speed application with challenging geometric conditions.

1.1 Research Goals

The goals of the research project were to:

- Establish the roadway characteristics that are suitable and warrant the installation of a warning system.
- Evaluate the technical feasibility of the system and monitor the operational performance.
- Determine the effectiveness of a downhill warning system at reducing run-away truck accidents.
- Determine the effectiveness of a downhill warning system at modifying driver behavior (i.e. adhering to the advisory speed message and reducing truck speed).
- Investigate the effectiveness of the system by reviewing public perception and the opinion of professional truck drivers.

Many benefits can be realized from completing this project. First, knowledge can be gained in the effectiveness, reliability, and applicability of the systems for other locations in British Columbia and the rest of Canada. Second, the reaction to the systems by the public and professional truck drivers can be understood to ensure acceptance of the systems. Ultimately, the benefits of the truck warning systems are the reduction in the targeted accidents (in this case runaway accidents) and the high costs associated with such incidents.

Once the effectiveness of the downhill system is determined, a credible economic evaluation can be established that could justify the installation of the system for other locations in Canada.

2 SYSTEM INSTALLATION

Neither truck downhill nor truck rollover warning systems had been installed in Canada. The Ministry of Transportation and Highways (MoTH) in British Columbia was interested in testing and evaluating the systems at problematic sites on the provincial road network. The Highway Safety Section of the Engineering Branch of MoTH was assigned the task of recommending possible sites based on truck accident statistics. Using the Highway Accident Database (HAS) and local knowledge, a number of sites were identified on the provincial highway system that had a higher than average frequency and/or severity of the two targeted accident types.

2.1 Site Selection

A site known as the Warfield Hill was identified as a suitable site to test the downhill truck warning system. The site is located on Route 3B, between Rossland and Trail and passes through the community of Warfield. The downgrade is very severe, reaching 10% grades, and is approximately 10 km in length.

The site accident history indicates that on average there have been 1.33 runaway related incidents per year (based on eight years of accident data). Additionally, the potential for a catastrophic incident is very high since the downgrade passes through the community of Warfield, where significant urban development exists adjacent or in very close proximity to the downgrade. In fact, the location is known for a very serious accident where a runaway truck demolished a house. Fortunately for the occupants of the house, they were not home at the time. This particular accident emphasized the potential damage a runaway accident could cause on this hill. Figure 2-1 shows the site of the accident. In the figure, note that the empty lot behind the barrier used to contain the aforementioned house.

Figure 2-1 Site of Warfield Hill Truck Runaway Accident

2.2 Benefit-Cost Ratio

The initial cost estimate for the downhill system at Warfield Hill is shown in Table 2-1, based on similar sites, albeit at a different location, prepared by the consultant, International Road Dynamics (IRD). The total cost of the system depends on the type of sign technology selected.

Table 2-1 Initial Cost Estimates for a Downhill Truck Speed Advisory System

Type of Costs	Low Range	High Range
Design, Equipment, and Supervision	$100,000	$100,000
System Installation Costs	$200,000	$200,000
System Sign Costs	$20,000	$100,000
TOTAL System Costs	$320,000	$400,000

The potential benefits accrued from a downhill warning system are the reduction in runaway related accidents and the costs associated with such incidents. To quantify the benefits, it was necessary to predict the reduction in runaway related accidents, determine the effectiveness of the system in preventing the targeted accidents, and determine the costs of a runaway incident. At the time of project inception, the quantification of the benefits could not be completed with a high degree of confidence. Using a series of assumptions on the effectiveness of the system and the cost of runaway accidents, a benefit-cost ratio of 10:1 was estimated (accident savings/system cost).

Since the B-C ratio was positive, B.C. MoTH contacted International Road Dynamics Ltd. (IRD) of Saskatoon, Saskatchewan, a Canadian supplier of automated truck warning systems. IRD was invited to submit a proposal for the design, development, and installation of a Downhill Truck Speed Advisory System (DTSAS) at the Warfield Hill between Rossland and Trail on Route 3B.

2.3 Project Delivery Considerations

In a turnkey project, the basic premise is that the owner is delivered a finished system from the vendor. The vendor carries out all necessary engineering and may publish engineering details. The future owner may have limited input into the finished product. Once the project is accepted and turned over, the owner operates the system and may or may not do their own maintenance. (An analogy would be the purchase of an automobile.)

Early in the project, MoTH decided that this would not be a 100% turnkey project. In a turnkey project there is the possibility that the owner of the system does not learn all the engineering aspects of the system. As well, jurisdiction-specific maintenance concerns may not be addressed in a turnkey system if the vendor is not familiar with that jurisdiction's maintenance practice. MoTH decided to carry out its own system maintenance, hence this was an important consideration in the decision.

Since this was the first project of its kind in B.C. and in Canada, MoTH wanted to work closely with the contractor to learn as much as possible about installation, operations, and maintenance of the system. The decision to do in-house maintenance also made it essential to acquire this knowledge. Since MoTH would be doing its own maintenance it was important that the system installation adhered as much as possible to MoTH design, installation, and equipment standards. Another factor that had to be considered was that the initial project timeframe was very tight. The project was initiated in October 1996, with an expected completion date of 31 March 1997. These factors necessitated that project roles and responsibilities between MoTH and IRD be very clearly defined. An interdisciplinary MoTH project team was assembled spanning project management, traffic engineering, electrical engineering from the Electrical Engineering Section (EES), regional and district operations and maintenance.

2.4 Concept of Operation

The DTSAS would weigh and classify long vehicles as they passed over a series of inductive loops and piezo-electric strips. The WIM computer in the DTSAS cabinet would record the speed, number of axles, and the weight per axle. The system would search predefined speed tables stored in the WIM computer to determine the selected advisory speed for that vehicle's number of axles and gross vehicle weight. The advisory speed would be displayed on a variable message sign for each truck. The trucker would read the message and be expected to act on it accordingly. If the system detected an error in measurement by the sensors, a default error message would be displayed.

During the project initiation meeting, the project sponsor raised the issue that with the DTSAS alone, the trucker does not receive any feedback as to actual speed. The project sponsor felt very strongly that the system's effectiveness would be increased if feedback could be given to the drivers.

The project team suggested that truckers would benefit from an additional system downhill from the DTSAS, which would notify them of their actual speed. The truckers would then have the benefit of this additional information when deciding whether they could reduce their speed if necessary or whether they should opt to use the runaway lane. It was agreed that an additional system of this type should be included in the cost estimate for the project. This system would be called the speed notification system (SNS)

The vendor specified performance parameters were:

- System shall accurately weigh at least 68% of all vehicles.
- System shall accurately classify at least 85% of all vehicles.
- Sign will activate 85% of the time for trucks.
- Piezo-electric sensors shall achieve an operating life of at least four years in 80% of cases.
- Overall system will meet the performance criteria outlined in American Standard Test Methods (ASTM) specification E1318-92 for weight-in-motion systems of Type II or better. For a Type II WIM the gross-vehicle weight must be within +/- 15%.

2.5 DTSAS Positioning

The Warfield Hill was very challenging with respect to system positioning. The hill extends from Rossland to Trail down Route 3B. In fact, the downgrade starts immediately after Route 3B passes through downtown Rossland. The only 0% grade segments are in downtown Rossland or at the weigh scale and brake check area one kilometre before the downgrade and before entering Rossland.

Another consideration at this location was that the posted speed limit was 50 km/h at the top of the hill where the road is very narrow, with closely spaced curves and increases to 60 km/h further downhill where the roadway widens. As well, there are large truck advisory signs for 20 km/h. The static truck advisory speed signs had their speeds determined by analysis of the MoTH Highway Safety Section, based on per axle loading of a truck loaded to the maximum allowable weight.

2.5.1 DTSAS General Positioning Criteria

A system should meet several basic criteria. It must be positioned sufficiently in advance of or early into the downgrade such that a truck on receiving the advisory speed message can still slow down to a safe descent speed by selecting the appropriate gear.

The roadway configuration and road surface must be within certain tolerances as outlined in ASTM E1318-92 *Standard Specification for Highway Weigh-In-Motion (WIM) Systems with User Requirements and Test Method*. The specified system was a Type II WIM designed for installation at traffic data-collection sites. It should be capable of accommodating highway vehicles moving at speeds from 10-70 mph (16 to 113 km/h). The specification prescribes a road configuration, which should minimize any possibility of vehicle and load shifting as it passes over the sensors. Specifically the longitudinal gradient and the cross-slope of the road surface for 45 m in advance or and beyond the WIM system sensors should not exceed 2%. Ideally the road should be flat and straight and the truck is travelling at a constant speed as it passes over the sensors.

2.5.2 DTSAS Positioning Options

Rossland is between the weigh scale/brake check area and the downgrade. Placing the DTSAS at the weigh scale and brake check area outside of Rossland would be ineffective since it was too far from the downgrade. The message would not have the immediate effect it would when displayed to the drivers at a location where they could in fact see the start of the downgrade. Additionally, there is a short downgrade between the weigh scale and Rossland, so drivers could possibly infer that the truck speed advisory was for the first small downgrade instead of the much more significant downgrade after Rossland, thereby diminishing the effect of an advisory message read up the road.

Placing the DTSAS in downtown Rossland would also be problematic. While there is a 0% grade, it is unlikely that trucks would be able to maintain a constant speed across the sensors (less than a 10% speed variation was required by IRD) because of Rossland downtown traffic and the angle parking that existed along the edge of the roadway.

The remaining option was to locate the system after downtown Rossland. Figure 2-2 shows the driver's view after exiting downtown Rossland after a 90 degree right turn. The figure shows the truck advisory signing as well as the fact that the downgrade starts immediately.

Figure 2-2 Start of the Warfield Hill

2.6 Chosen DTSAS Site

The remaining option for site selection was to find a location on the downgrade. It was essential that the location be near the beginning of the downgrade before the truck has gained too much speed and is still able to get into the appropriate gear. At the same time, it was necessary to come as close as possible to the criteria laid out in the ASTM specification. The added challenge was that the upper section has multiple curves.

After much investigation by MoTH and IRD staff, it was agreed that the best location was on a short tangent section approximately 400 m after the start of the downgrade. The chosen location was the only section near the beginning of the downgrade where field observations showed that trucks maintained a constant speed. Other sections had more closely spaced curves for which it was observed that most trucks applied their brakes to some degree and hence there was a likelihood of not maintaining a constant speed over the sensors. Figure 2-3 shows the location of the sensors that are in the roadway adjacent to the pole. Note that from this position the driver cannot see the variable message sign. To alert the driver to active advisory information, there is an advisory sign “TRUCK ADVISORY SYSTEM AHEAD” (shown covered in the figure). It was decided that since the system and its active advisory messages were unique, it was necessary to alert the driver to expect this information.

Figure 2-3 Road Segment with Sensors (located adjacent to the pole)

The grade at the site was approximately 8%. In their proposal, IRD indicated that this would result in some loss of accuracy for the WIM system, but that this would be compensated for by installing an additional piezo-electric sensor and by adjustments in the software and calibration of the system. While the grade was greater than what would normally be used for a WIM system, IRD felt that since the grade was constant then grade compensation was possible.

The location was sufficiently near the start of the downgrade so that brakes should still be fresh enough to allow drivers to reduce speed and shift gears before proceeding too far down the hill. Figure 2-6 shows a portion of the electrical site plan for the DTSAS installation.

2.7 SNS Positioning

The positioning criteria for the SNS were simpler to meet than for the DTSAS. Since the SNS was a MoTH requirement, IRD did not have any pre-defined criteria for its installation. The project team developed the following criteria:

- For accurate speed measurement the inductive detection loops must be positioned on a portion of the roadway where it is unlikely that vehicles will be changing speed.

- The SNS should be located so that once the vehicle's measured speed is displayed, there should be sufficient time and distance for the driver to take action shortly thereafter on their descent.

It would not have been desirable to measure the truck speed too soon after the DTSAS. In fact, the geometry of the hill helped determine its location. The SNS was located at a section of the downhill where the roadway opens up to two lanes downhill and one lane uphill. As well, the grade is not as severe as at the start of the downgrade. This change in the roadway could cause the driver to relax and think that the grade and driving will be gentler from there on. The downgrade does continue for several more kilometres so if trucks allow their speed to increase they would experience difficulty negotiating subsequent curves. Hence, it was decided to locate the SNS in the segment where the roadway initially opens up.

This location also satisfied the requirement that the driver be able to use the information once presented with it. At this location the speed notification system is approximately 1.2 km uphill from the truck runaway lane. When the driver passes over the detection loops, the measured truck speed will be displayed on the overhead flip disk sign. Approximately 200 m downstream, the driver will see the truck warning sign advising that the runaway lane is 1000 m ahead. At this point drivers will be able to decide whether, for the measured speed, they can safely descend the hill or whether they should opt to use the runaway lane. The relative positioning of the SNS components is shown in the electrical site plan in Figure 2-7.

In Figure 2-5, the SNS is shown in operation. Note that the system has been triggered by a truck and trailer combination that appear to the system as one long vehicle.

2.8 Work Plan

The initial schedule called for completion of the project by 31 March 1997. This area has a history of long winter conditions. Hence, to meet the deadline, it was intended to have as much of the system as possible installed in the fall of 1996.

MoTH arranged for a survey of the roadway at the proposed system locations. Using this information and some generic schematic drawing provided by IRD, MoTH Electrical completed an initial electrical site plan. This site plan was forwarded to IRD for review. IRD promptly provided technical feedback as to exact loop and piezo-electric sensor locations. Drawings were finalized and MoTH Electrical assembled the tender documents for the in-ground works. The contracts for these works were then let using standard MoTH contracting procedures. The inground works were installed in October 1997, as per Figures 2-6 and 2-7. The inground works consisted of the sensors, pole bases, and conduit runs from the electronics cabinets to the signs.

This approach was chosen for two reasons. The foremost reason was the short timeline, which necessitated a collaborative approach. IRD did not have any recent experience with electrical designers or installers who regularly did MoTH work. Second, MoTH wanted to learn as much as possible about this system. Hence by MoTH having a high degree of involvement, staff were able to gain a greater understanding of the system than if it was a turnkey project.

The above-ground works and the installation of the electronics were scheduled for the spring of 1997, as soon as weather would allow. These above-ground works consisted of the installation of the poles, service panels, and variable message signs. MoTH prepared the contract documents and let the above-ground installation contract in spring 1997.

The time between the in-ground and above-ground works allowed IRD to assemble the necessary electronics for both the DTSAS and the SNS and carry out factory acceptance testing.

It was decided that MoTH would supply IRD with MoTH standard cabinets to be fitted with the IRD electronics. The consensus of the MoTH electrical staff was that using MoTH standard cabinets would help enhance the consistency of maintenance. Upon review of the physical space requirements for the IRD electronics, it was found that all the components could fit within MoTH standard pole-mounted cabinets. The advantage of using pole mounted cabinets is that they tend to be smaller, do not require an additional base to be poured, and save several small conduit runs as would have to be installed between a pole and a cabinet. Pole-mounted cabinets have another distinct advantage in areas where there is significant snow accumulation: once the pole is located, the technician will know where the cabinet is. On the other hand, with separate, base-mounted cabinets, it may not be a simple matter of finding the cabinet if it is covered with accumulated or snowplow driven snow.

2.9 Sign Selection

Two separate signs were required for the Warfield Hill. The sign for the DTSAS needed to be able to display multiple messages. The SNS was only required to display the measured truck speed.

2.9.1 DTSAS Sign

When considering the DTSAS sign, there were two primary factors to address. The message on the sign must be conspicuous and directed to the trucker in question. MoTH already has a sizable inventory of variable message signs throughout the province. MoTH's current inventory of variable message signs are Telespot signs, operated through Telespot's MOSYS software. It was decided to select a Telespot sign to ensure that it would fit in with the Ministry's existing system. The sign chosen was a LED enhanced flip disc variable message sign with two lines of 14 characters, each approximately 25 cm high.

The primary purpose of the sign was to display downhill truck speed advisory messages to truckers. There was an additional requirement to display other messages such as road condition advisories (for example, ICY CONDITIONS). MoTH made it a requirement that the sign message from the DTSAS could be over-ridden if need be by a message from our Provincial Road Conditions Centre. Possible scenarios, which necessitate this requirement, would be an accident or partial lane closure farther down the hill. The VMS sign was manufactured by Telespot. MoTH supplied a pole-mounted cabinet into which Telespot fitted the sign control electronics.

The location of the VMS sign must be sufficiently downstream of the WIM computer and sensors so that the WIM computer has enough time to process the data and send the appropriate advisory speed selection back to the VMS. The sign is shown in Figure 2-4.

Figure 2-4 Message Sign Displaying Truck Advisory Speed

2.9.2 SNS Sign

The sign requirements for the SNS were simpler. It was decided that the system would only be required to display the measured speed. Hence, a fixed message sign would be used with two flip disk modules to display the speed digits. The sign message would read “XX Measured Truck Speed” as shown in Figure 2-5. The location of the speed notification sign is based on the same computer processing time requirements as for the DTSAS. For the SNS there was a further constraint that the sign be uphill from the truck runaway lane advisory signing. The SNS sign was placed 200 m uphill from the first truck runaway lane distance sign. The static signboard was manufactured by the Provincial Sign Shop. Telespot provided the flip disk modules to MoTH who arranged for their installation into the signboard.

Figure 2-5 SNS Displaying Measured Truck Speed

2.10 Speed Table Development

The speed tables were developed by the contractor, IRD, and reviewed by the Ministry. A series of FHWA reports [2,3,4] were used as references for the speed table development.

The safe speeds used in the DTSAS primarily depend on grade length and steepness, total truck weight, classification, and speed. They also depend on outside air temperature, ambient wind conditions, initial brake temperature at the top of the hill, and engine RPM used in the descent. To obtain accurate and reflective speed values for each weight category, it is crucial to accurately determine the steepness and length of the grade.

The Ministry provided IRD with grade profiles for the hill. As well, a video log of the hill was provided on a VHS cassette. The video log provides a driver's eye view of the roadway. Additionally, one of the recorded parameters is the grade. With the video log frames being recorded every 20 m, this provides another accurate record of how the grade changes. IRD used this grade-specific information along with the B.C. truck classification, that had been used previously on the C-HELP project, to develop the speed tables. Speed tables were developed for two through nine axle trucks.

The speeds were calculated to the nearest integer. However, it would not be practical to advise such an exact speed (for example, ADVISORY 18 km/h). Hence, it was decided to round the calculated advisory speeds down to the nearest 5 km/h. Rounding down provides a somewhat more conservative advisory speed, whereas rounding up would result in an advisory speed higher than what the calculations indicate would be prudent. The system was configured to display advisory speeds from 5 km/h to the posted speed limit of 50 km/h in 5 km/h increments.

2.11 Final Concept of System Operations

The final concept of operations for the DTSAS and SNS are explained in detail in this section. As previously outlined, the DTSAS would weigh and classify trucks, determine an advisory speed, and display it to that driver on a variable message sign.

The downgrade of the Warfield Hill starts immediately after the vehicles make a 90-degree right turn exiting downtown Rossland. The trucker is immediately presented with a TRUCK ADVISORY 20 km/h sign as shown in Figure 2-2. Following the TRUCK ADVISORY speed signs are downgrade warning signs.

2.11.1 DTSAS Operations Details

The posted speed on this section is 50 km/h. Field studies showed that loaded trucks averaged 20-30 km/h when they passed over the sensor section whereas unloaded trucks would travel at the posted speed. As the trucks approached the sensors the trucker would see a warning sign “TRUCK ADVISORY SYSTEM AHEAD.” The purpose of this sign was to alert the trucker to the fact that they would be presented with advisory information. It was felt that this “heads up” for the driver was necessary due to the unique nature of the system. The sign was to remain covered until the system was commissioned.

A typical DTSAS installation has two piezo-electric sensors. The three piezo-electric sensors were recommended by IRD to help compensate for the 8% grade. Valid readings must be achieved on all three sensors, otherwise an error is registered. The sensor configuration is outlined in Figure 2-6. Note that the piezo-electric sensors are labeled as axle sensors.

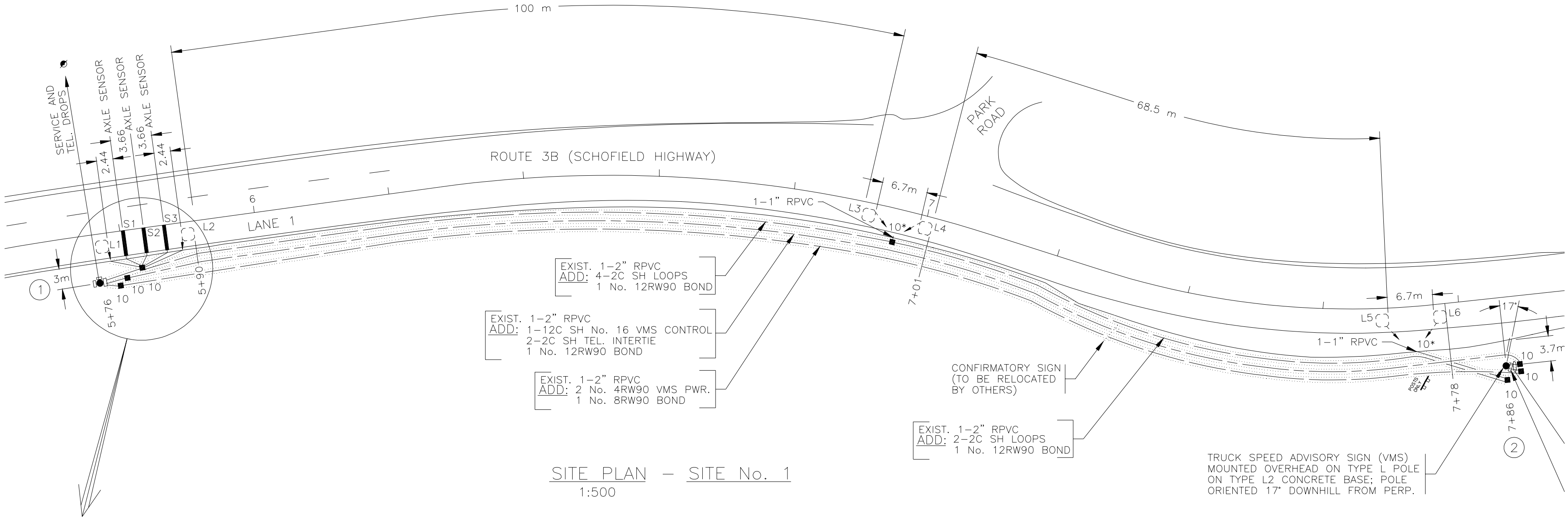

Figure 2-6 Electrical Site Plan for DTSAS

Once the truck had passed over the sensors, the driver had to negotiate a turn to the right. There was insufficient distance between the sensors and the curve to place the VMS sign, hence the sign had to be after the curve. The sign is blank until the truck passes over the display loops at which point the specific advisory message for that truck is shown to the driver. Leaving the VMS blank until the truck triggers the on-loops has the effect of emphasizing that the message is specific to that particular truck. The message remains displayed on the VMS until the off-loops are triggered. The display operation is shown in Figure 2-4.

2.11.1.1 Advisory Messages for Special Circumstances

When an error is registered while the vehicle is passing over the sensors, the VMS sign will display a default message. Initial thoughts were to simply inform the driver that it was not possible to display an advisory message. Possible messages in that case would be “TRUCK INFO UNAVAILABLE.” While this would inform drivers that an advisory speed message could not be generated, it did not provide them with any useful information for descending the hill. It was then decided that it would be better to provide information further reinforcing the downhill to the driver. Hence, the default message in case of an error was “STEEP Grades for 10 km.”

The other scenario that was considered was a truck descending the slope at a speed slower than its calculated advisory speed. This scenario could occur when the truck was not loaded or lightly loaded and the driver was following the static truck advisory speed sign. In this case the system would display the speed at which the truck crossed the sensors (to the nearest 5 km/h). The reason for this function was not to encourage drivers to increase their speed.

When the truck advisory speed tables were being developed by IRD, it became clear that certain unloaded trucks could theoretically descend the downgrade at a speed greater than the posted 50 km/h. Further down the hill, in fact, the speed limit does increase to 60 km/h where the roadway widens. Advising a descent speed faster than the posted speed in the immediate section would not be prudent, Hence, it was decided that the maximum allowable truck advisory speed under any circumstances would be the posted speed of 50 km/h.

2.11.2 SNS Operations Details

The Speed Notification System’s operation is inherently simple. As a truck passes over the two inductive loops its speed is determined by dividing the distance between the loops by the time the vehicle passes over the leading edge of both loops. Since the purpose of the system was only to determine truck speed, the system was configured such that speeds would only be displayed for a vehicle if it covered both loops simultaneously. If this constraint were not included in the system, the sign would continuously be changing the measured speed message with each passing vehicle either passenger cars or trucks. Hence, truckers would not be able to tell with any certainty whether a message was meant for them or for a nearby passenger vehicle. By only displaying the measured speed for trucks, there is a greater certainty of truckers recognizing that the message is directed at them.

The roadway widens to two lanes downhill immediately before the SNS. This widening requires that both lanes be equipped with inductive loops. The software is configured such that, if there are valid readings from both lanes simultaneously, the higher of the two readings would be displayed. During acceptance testing it was observed that the majority of trucks stay in the slow lane. Instances of trucks passing other trucks on the downgrade were infrequent and limited to unloaded trucks passing slower loaded trucks.

The SNS functions continuously, regardless of the weather conditions.

2.12 DTSAS and SNS Installation

Installation was completed in spring 1997. MoTH regional electrical staff as well as electrical engineering section staff commissioned the VMS sign and tested its operation via the Provincial Road Conditions Centre. IRD technicians commissioned the DTSAS and SNS electronics and tested over-all system integrity.

Once it was determined that all components were functioning, the IRD representatives proceeded with calibration.

2.13 Calibration

For the calibration of the DTSAS a dump truck loaded with gravel was used. The calibration procedure required that a truck of known dimensions and weight drive across the piezo-electric sensors at a constant speed over many repetitive runs. A loaded dump truck was hired locally and driven through the weigh scale to determine its per axle weight. As well, the dimensions between the axles were measured. The IRD representative instructed the driver to maintain a constant speed as he drove over the sensors. The calibration was completed during the midday period.

For the SNS calibration, arrangements were made with the local RCMP detachment for the loan of a radar gun. The RCMP parked a cruiser with the radar pointed so that it would measure the speed of vehicles at the point where they crossed the downstream speed sensor. In this manner the speed displayed on the radar gun should match the speed of the SNS. The SNS was calibrated to +/- 1 km/hr of the RCMP radar gun by IRD. MoTH staff confirmed the accuracy of the calibration.

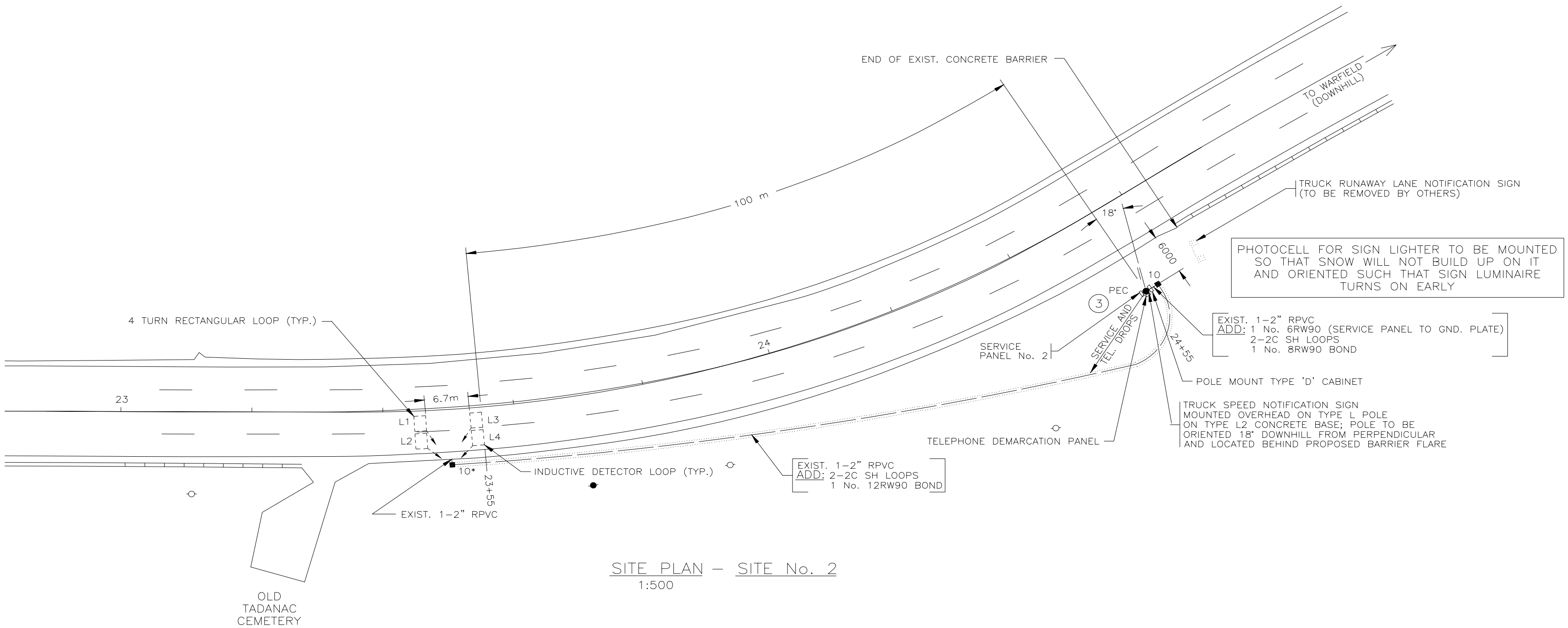

Figure 2-7 Electrical Site Plan of SNS

3 TESTS

There were two parts to Ministry acceptance testing. The first part was testing that the WIM met the necessary specification. The second part was ensuring that the sign displayed the appropriate message for the WIM information and that the sign could be over-ridden and controlled remotely from the Provincial Road Conditions Centre.

During the testing phase, informational bulletins were distributed from the Rossland weigh scale. As well, MoTH staff verbally briefed many drivers passing through the weigh scale as to the reasons for the system. As many drivers travel the Warfield Hill repeatedly, their verbal opinions were sought at subsequent stops at the weigh scale.

3.1 Weigh-In-Motion Testing

To test the accuracy of the WIM system, it was important to know the true weight of trucks crossing the sensors. To achieve this the Rossland weigh scale was opened for each MoTH testing session. At the weigh scale, the truck's weight, its company name and company identification number (if applicable) were recorded. The same information was recorded at the DTSAS site as at the weigh scale. This information then correlated after each testing session. It should be noted that not all the trucks that use the Warfield Hill pass through the Rossland Weigh Scale. There are a number of trucks which come up from Trail, B.C., to make deliveries in Rossland and then go back down the hill. These trucks may have gone through the Castelgar weigh scale but it was not feasible to collect this information. On each testing session it was found that approximately 30-40 trucks passed through the Rossland weigh scale and proceeded down the hill and through the DTSAS system.

3.2 VMS Testing

The VMS testing consisted of ensuring that the appropriate advisory message was displayed for the weight and classification determined by the WIM computer. In each testing session the message displayed for each truck was cross-referenced with the measured weight and number of axles shown on the WIM computer display. This was compared with a hard-copy of the speed tables.

The over-ride from the Provincial Road Conditions Centre was tested by contacting the Centre by cellular phone and instructing them to place and remove a variety of test messages on the VMS sign. In each case it was ascertained whether or not the DTSAS messages were suppressed during the over-ride and whether the DTSAS messages resumed being displayed after the over-ride message was removed.

3.3 SNS Sign Testing

The testing for the SNS sign was very simple. Once the system was calibrated the display on the SNS computer was compared with the number displayed on the flip disc modules.

4 RESULTS

The Ministry carried out a number of testing sessions. Initial WIM testing sessions were hampered by several technical difficulties, described below. Sign testing was only necessary once.

4.1 WIM Results

Initial testing determined that a substantial number of trucks that passed over the sensors generated error messages in the WIM computer. Analysis of the errors and further observation of the trucks travelling past the site revealed that trucks were tracking somewhat across the centre-line. It was determined that this was a result of the centre-line being very badly faded due to an extremely harsh winter that resulted in a very faint centre-line marking. This section of the highway was scheduled for centre-line repainting later in the summer. Also, the concrete barrier on the downhill side had a vehicle parked at the end on the shoulder that happened to be in the proximity of the sensors. As the centre-line did not stand out significantly, there was a tendency to use more of the roadway width, which at that location was one lane downhill and two lanes uphill. The uphill traffic was predominantly using the shoulder lane, leaving downhill traffic with the impression that they had more width at their disposal.

For later testing sessions, yellow flexible plastic delineators, used by paving crews prior to pavement marking, were placed on the centre-line at five-metre intervals. As well, no vehicles were parked near the sensors. This resulted in a substantial reduction in the number of errors due to trucks tracking off the sensors. Afterwards *on-scale missed* errors were no longer an issue. At a later date recessed centre-line reflectors were installed. These significantly improved delineation, and since they were recessed, would survive the winter.

As testing continued it was found that the overall percentage error in gross vehicle weight was greater than that specified in IRD's proposal. Detailed analysis of the testing data revealed that the accuracy varied greatly with the time of day. The highest degree of accuracy for trucks occurred immediately after noon which corresponded closely to the time of day when calibration took place. The poorest results occurred in the early morning. Hence it appeared that system performance improved as the temperature increased during the day. The daily change in asphalt temperature was made even more extreme due to the fact that the highway section containing the sensors is in full shade in the morning and full sun by mid-day. This led MoTH to suspect that the problem was with the temperature sensor calibration. IRD ascertained that the temperature sensor needed to have 50 trucks in each temperature range before the auto-calibration would be correct. At the time of the acceptance testing, an insufficient number of trucks would have passed by in the lower temperature ranges. It was likely that the mid-day readings were good because that corresponded to the time of day of calibration. At this point, it was decided to resume testing several weeks later.

The next round of acceptance testing again showed that the errors in truck weights varied with the asphalt temperature. This reinforced the notion that the temperature sensor and or temperature adjustments were inadequate. IRD decided to calibrate at different temperatures in order to overcome the temperature dependency problem. Once IRD completed this task, the Ministry again tested the system and found that the performance of the system exceeded the specifications in the proposal with an average percentage difference in gross vehicle weight of only 8% over all trucks read correctly by the system. (Note that errors such as significant speed difference caused by drivers braking while their vehicle is over the sensors – are beyond system control.) These results showed that system performance was within the specified range during the temperatures experienced at the time of testing, the middle of the summer.

Given the earlier problem of temperature dependency, the MoTH was concerned about system performance as temperatures decreased. System performance at lower temperatures was a significant unknown since the only way we could test that was during lower temperatures in the fall.

IRD carried out cold weather calibration down to 5°C in October. Shortly thereafter, MoTH undertook cold weather testing. At this time the centre-line had been repainted and delineation was very good. The temperatures during the testing period ranged from –1°C to 10°C. Testing showed that the warning message, *Significant Weight Difference,* was received for many trucks. Diagnostics revealed that one of the three piezo-electric sensors was weighing differently from the others in some cases, resulting in the warning message. Investigation of the piezo-electric sensors in the roadway showed that sensor #3 appeared to be starting to pop out of the asphalt and that sensor #1 showed signs that it might as well. It was later determined that during installation the sensors had been weighted down in the ruts in order to achieve the required depth across the lane. The resulting configuration is shown in Figure 4-1. The correct installation was to place the sensors at the required depth in the ruts without weighting the sensors. Consequently, the sensors in the non-rutted portions of the lane would be deeper than the installation specification requires. However, the deeper installation is inconsequential given that the vast majority of vehicles track through the ruts. The correct installation is shown in Figure 4-2.

Nevertheless, for the other WIM readings which did not display warning messages, the percentage difference in GVW was greater than outlined in IRD's proposal. This round of testing showed that the cold weather system performance did not meet the specification.

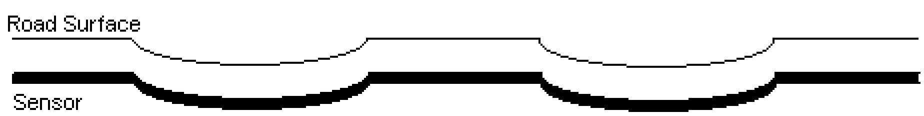

Figure 4-1 Incorrect Sensor Installation

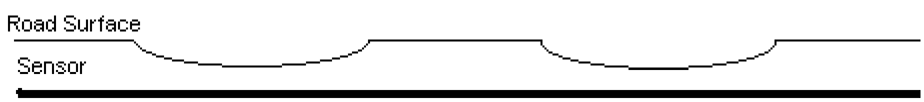

Figure 4-2 Correct Sensor Installation

The test results were reviewed by IRD, who determined that a number of factors, when taken together, were hampering system performance. Foremost was the slow speed at which the trucks were rolling over the sensors. The static truck speed advisory signing advises a speed of 20 km/h. Loaded trucks operate at close to that advisory speed. The operating speeds for trucks are very close to the lower speed threshold for Type II WIM. The slower speed affects the response of the piezo-electric sensors. The effect of the low speed when combined with the 8% grade and the cold temperatures results in the accuracy of the WIM system being outside specified limits.

IRD came up with a possible solution, offering to install a bending plate in place of the piezo-electric sensors. Bending plates have superior accuracy at low speeds and are unaffected by temperature. However bending plates are installed within a concrete vault. MoTH's roadway was asphalt. There was significant concern about the behaviour of the junction of the asphalt and the concrete vault. Since the two materials wear at different rates, MoTH felt that there was a distinct possibility that unequal wear at this point would result in the truck and its load experiencing a bump immediately before the bending plate. This would then introduce errors into the system. MoTH felt that this would call for another maintenance requirement and constant monitoring of the system and sensor status in the roadway.

4.2 DTSAS VMS Results

It was found that for a given weight and axle configuration registered on the WIM computer, the VMS always displayed the correct message. When an error occurred in the WIM data such as the truck missing a sensor due to off-tracking then the default error message was displayed. The Provincial Road Conditions Centre was able to display a message remotely and over-ride the DTSAS messages. When the message was removed, the DTSAS resumed displaying truck advisory messages.

4.3 SNS Results

It was found that the SNS sign always displayed speed that was calculated by the SNS computer.

5 CONCLUSIONS

The results indicated that the DTSAS had acceptable performance during summer months when the temperatures were warm. However, cold weather testing did not meet the requirements of the specification. Only achieving the necessary system accuracy during warm summer months would severely limit the application and acceptance. There were also operational concerns: district staff would be required to continuously monitor temperatures to determine whether the system should be used. Given these considerations, MoTH decided that the DTSAS system would not be used for displaying truck speed advisory messages at this site. Since the system did not meet the performance specification, the project was closed and no further testing took place.

IRD's DTSAS had never been implemented at a site with characteristics such as those at the Warfield Hill. The slow speed of trucks crossing the sensors, the 8% grade, and the extreme temperature range worked together to provide an unfavourable environment for the system. Since there was more than one factor working against the system and they all were linked at this site, it was not possible to isolate one from the other.

As a result of its investigations, IRD concluded that, given the conditions at the site, the original specification would not be achieved for trucks travelling at less than 40 km/h and when the temperature was less than 5°C. MoTH accepts this conclusion.

As a result of not proceeding past the acceptance testing stage due to the limitations of the site and system, it was not possible to achieve the research goals relating to the effectiveness of the system since full deployment was not undertaken. It was determined that the roadway characteristics at this specific location were not suitable for a system of this type. However, the testing did indicate that the necessary accuracy is achievable under certain conditions. This is a positive indicator that with more favourable geometrics and a higher posted speed, the system could be technically and operationally feasible. The technology, aside from the WIM with the piezo-electric sensors on the downgrade, worked very well.

The truck driver perception of the system was mixed. The Warfield Hill sees a large percentage of repeat drivers every week. A segment of this group felt that, as seasoned drivers continually driving the same route, they did not need this type of system. Within the same group there were drivers who expressed their opinion that any measure that enhanced safety was welcome. A frequently voiced opinion was that the system would most benefit new drivers unfamiliar with the hill. This is likely true and it is further supported by the fact that during system installation there was one instance of a truck driver unfamiliar with the hill being stopped by the RCMP one-third of the way down with smoking brakes.

In summary, there were valuable lessons learned on this project, both from the view of system suitability as well as engineering considerations that must be addressed with respect to system placement, delineation, and signage. While the DTSAS is not implemented on the hill, parts of the system continue to provide valuable advisory information to truck drivers.

The VMS at the Warfield Hill is still used to provide grade advisory information, "STEEP Grades for 10 km," to all drivers. Road condition information can be displayed on the VMS at the discretion of the district staff via the Provincial Road Conditions Centre.

The SNS continues to accurately measure and display truck speed, thus providing truck drivers with critical information as they approach the runaway lane.

6 RECOMMENDATIONS

This research project provided valuable lessons.

As a result of its investigations, IRD recommended that a bending plate be installed in place of the piezo-electric sensors for WIM measurements. Bending plates have superior accuracy at low speeds and are unaffected by temperature. The performance of the DTSAS using bending plates for WIM may provide improved accuracy and reliability albeit at potentially increased maintenance costs. The installation and evaluation of bending plates for DTSAS WIM were beyond the scope of this project.

The piezo-electric sensors should be placed at the required depth in the portion of the lane the vehicles are using. In the case where the road is rutted, the piezo-electric sensors should be placed at the required depth from the bottom of the ruts. The sensors would be deeper than the required depth between the ruts, but there will be minimal effects since vehicle wheels do not track through that part of the lane. The sensors should not be weighted or forced to conform to the contour of the road as this will likely cause them to loosen or pop out of the road eventually.

The roadway on the approaches to the sensors should be clearly delineated in order to improve guidance such that trucks will consistently track over the sensors to achieve valid axle weight measurements.

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