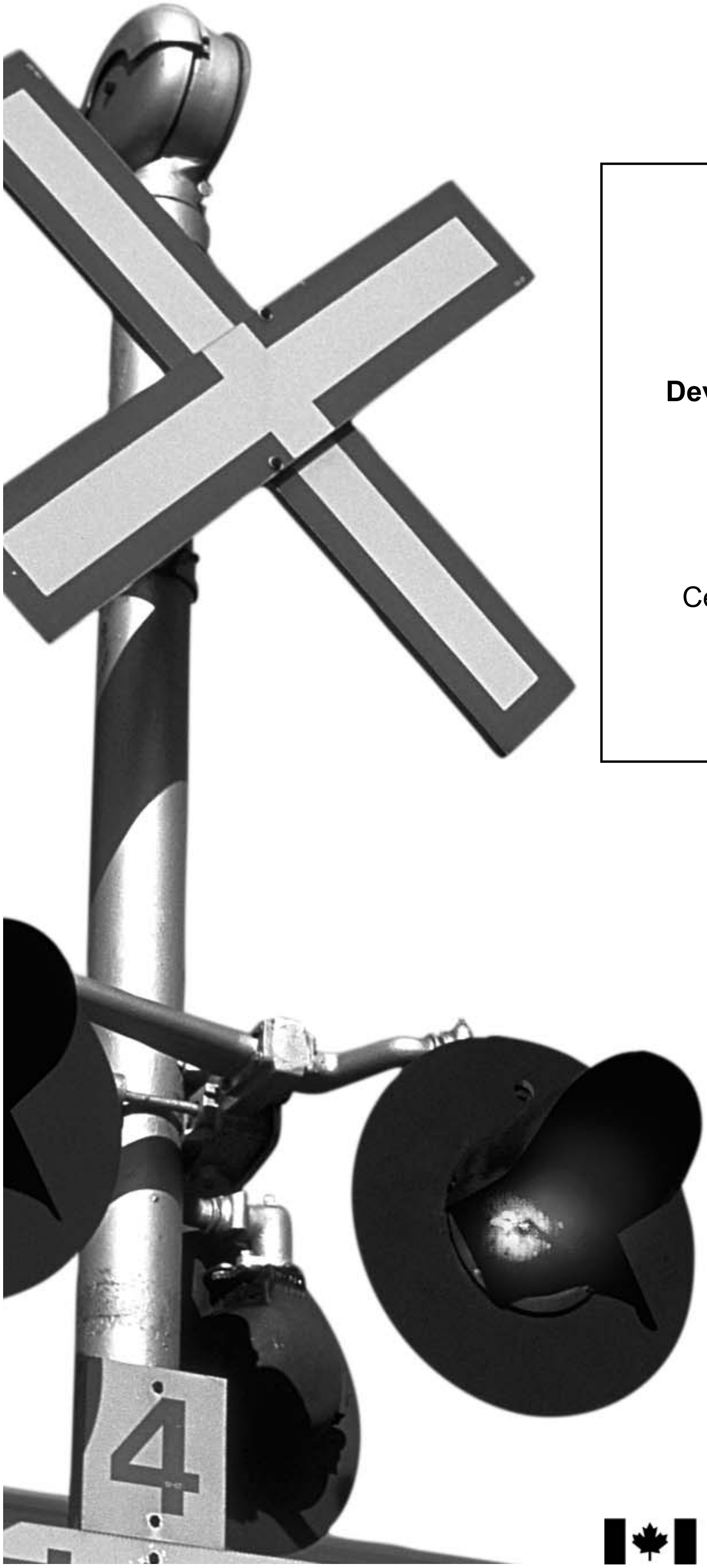
Highway-Railway GRADE CROSSING RESEARCH



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IMPACT OF HEAVY VEHICLES ON CROSSING SAFETY –
Development of an Adapted Design Tool

Prepared for
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by
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IMPACT OF HEAVY VEHICLES ON CROSSING SAFETY – Development of an Adapted Design Tool

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16. Abstract

As part of a study commissioned by Transport Quebec aimed at evaluating the impact of heavy vehicles on the safety of railway crossings, we tested various classes of heavy vehicles to determine their acceleration and braking performances used in calculating sight triangles at railway crossings. After being applied in a mathematical model, the acceleration testing results were used to develop a railway crossings design and verification tool to be integrated into the RTD 10 standards, entitled "Road/Railway Grade Crossings: Technical Standards and Inspection, Testing and Maintenance Requirements".

Recommendations were presented on integrating the tool into RTD 10, using uniform units of measure, removing fixed crossing reference times in RTD 10, and abolishing regulations restricting the shifting of gears while crossing railway tracks.

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16. Résumé

Dans le cadre de ce projet réalisé à la demande de Transports Québec et visant à mesurer l'impact des véhicules lourds sur la sécurité aux passages à niveau, nous avons procédé à des essais pour mesurer les temps d'accélération et les distances de freinage de diverses classes de véhicules lourds utilisées dans le calcul des triangles de visibilité des passages à niveau. Les résultats obtenus, après avoir été exploités dans un modèle mathématique ont été utilisés pour développer un outil de conception et de vérification des passages à niveau qui pourra être intégré au projet de norme RTD 10 intitulé «Normes techniques et exigences concernant l'inspection, les essais et l'entretien des passages à niveau rail-route».

Des recommandations ont été émises au sujet de l'intégration de l'outil au projet RTD 10, de l'utilisation d'unités de mesures uniformes et du retrait des temps de référence fixes dans le RTD 10, ainsi que de l'abolition des règlements portant sur l'interdiction de changer de vitesse aux passages à niveau.

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This study is a part of the Highway-Railway Grade Crossing Research Program, an undertaking sponsored by Transport Canada, major Canadian railways, and several provincial authorities. The program is a component of Direction 2006, a cooperative initiative with the goal of halving grade crossing accidents by 2006.

SUMMARY

As part of a study commissioned by Transport Quebec aimed at evaluating the impact of commercial vehicles on the safety of railway crossings, various heavy vehicles were tested (buses, straight trucks and tractor-trailer combinations) in order to determine their acceleration and braking performance. The goal of these tests was to identify typical braking and acceleration performances of various classes of commercial vehicles used in the calculation of sight triangles at railway crossings. Results were used to develop a railway crossing design and verification tool to be integrated in the new RTD 10 standard.

A total of 21 commercial vehicles were tested during the period of 3 August 2002 to 11 February 2003. Testing was performed in Quebec on the test tracks of the Centre de formation en transport routier (CFTR) in Saint-Janvier, on the test tracks of PMG Technologies in Blainville, on eight railway crossings located in the area between Blainville and St-Jérôme, and on a railway crossing located in a logging area north of La Tuque. Brake tests were conducted on a wet asphalt surface while acceleration tests were conducted on a dry asphalt surface and on dry railway crossing sites. Acceleration tests from the stop line to the crossing's safe clearance line were also performed at each of the nine typical railway crossings.

The results of these tests were used in the development of a mathematical model of heavy vehicle acceleration according to the vehicles' technical specifications. The model helped to identify various classes of commercial vehicles to be used and to determine the worst acceleration performances associated with each class of vehicle. Brake testing results helped to identify typical braking performances of these heavy vehicles. The acceleration and braking performances were then combined with various criteria associated with driver perception and reaction times as well as driver performance and skill during gear shifting and braking. Safety margins were also added to driver performances and vehicle approach speeds in order to better reflect real situations.

Taken together, these typical performance parameters were used to calculate minimum sightline distances or sight triangles according to the class of commercial vehicle as well as the roadway profile of the approach and exit of the crossing. The crossing times are presented on reference graphs and the stopping sight distances in the form of tables. These graphs and tables present typical roadway profiles with 2% and 5% grades. For all other roadway profiles, a simple extrapolation can be performed. This procedure can be adapted to commercial vehicles of all configurations, weights and dimensions, and operational characteristics, as well as all road conditions and all train and vehicle speeds, under normal weather conditions. This tool thus permits the calculation of sight triangles and can be integrated into the draft RTD 10 regulation issued by Transport Canada's Rail Safety Directorate on 24 July 2001 titled *Grade Crossing Regulations - Maintenance, Inspection and Testing*.

The final tool consists of stopping sight distance (SSD) tables and crossing time reference graphs. The tables present the SSD according to the type of braking system (i.e., ABS), the roadway profile, and the posted speed limit. The graphs present the crossing times according to the class of vehicle, the roadway profile, the safe clearance distance over the crossing, and the possibility of changing gears. Methods of using the graphs for tanker trucks, grade crossings near an intersection, and grade crossing surfaces in poor condition are also offered.

Finally, some recommendations are made concerning the integration of the tool into RTD 10, the use of standard units of measure and fixed crossing reference times in RTD 10, and the repeal of government legislation prohibiting the changing of gears when going over railway tracks.

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INTRODUCTION

Approximately 10% of all accidents at grade crossings involve heavy vehicles, and many of these collisions result from visibility problems. Since vehicles transporting dangerous goods must stop before going over a crossing, at least in Quebec and the United States, truck drivers must have adequate visibility when stopped so their vehicles can then cross the railway tracks without colliding with a train. In addition, heavy vehicles not governed by this rule must be able to stop at grade crossings that are not equipped with lights or sound signals when a train is approaching. To this end, the method of designing and verifying railways establishes a sight triangle in which the length of road equals the sum of the braking distance plus the distance travelled during the driver's perception and reaction time (stopping sight distance). The length of railway must equal the distance travelled by the train at normal speed during the time it takes a heavy vehicle to cover, at its initial speed, the total of the stopping sight distance, the distance required to clear the crossing, and the length of the vehicle.

However, while crossing design standards have remained unchanged for a very long time, road vehicles have undergone a number of technical changes. This means that some aspects of these standards are potentially outdated. Consequently, as part of a project commissioned by Transport Quebec aimed at evaluating the impact of heavy vehicles on the safety of railway crossings, various heavy vehicles (buses, trucks and tractor-trailers) were tested to measure their acceleration times and braking distances. The goal of these tests was to identify the typical braking and acceleration performances of various classes of heavy vehicles used in calculating sight triangles at railway crossings. The results were then used to validate a mathematical model of heavy vehicle acceleration. This model and the results of the various tests, including the braking tests and site tests at railway crossings were then used to develop a railway crossing design and assessment tool that could be integrated into the new RTD 10 standard. The tool developed in the project makes it possible to establish sight triangles adapted to commercial vehicles of all weights, sizes and operating characteristics, road conditions, truck and train speeds, under normal weather conditions.

1. GRADE CROSSING SAFETY – SITUATION OVERVIEW

Many studies, databases and scientific publications on road safety at grade crossings were consulted – in particular those dealing with the use of grade crossings by heavy vehicles. These sources of information make it possible to provide an overview of the current situation. The literature review presented in this chapter first identifies various general aspects of grade crossing safety and the regulatory organizations that play a role in this area. Next are presented accident statistics and various regulations that govern or affect grade crossing safety. Then the main topic, the impact of heavy vehicles on crossing safety is discussed using statistics and regulations that govern these types of vehicles, followed by a discussion of the causes and contributing factors of collisions listed in the literature. Finally, the results of earlier studies on heavy vehicle performances (acceleration and braking) are presented and commented on.

Grade crossings are considered to be road intersections, even if trains do not necessarily stop or cannot physically stop in the case of an emergency because of their often-high approach speed. The risks if a vehicle is on the tracks are thus considerable. Collisions at grade crossings, as elsewhere, are rarely the result of a single cause, but rather of a set of contributing factors. Thus, this is a multi-facetted problem involving technical aspects of the vehicles and the environment, as well as human and social factors. Among the technical aspects, it is clear that the configuration of grade crossings and the operating characteristics of vehicles can produce certain risks for road vehicle drivers crossing a railway track. For instance, contributing factors in collisions include the visibility of the trains, warning times, the angle between the road and the tracks, signalling, vehicle braking and acceleration performance, the quality of the crossing surface, or the presence of multiple tracks. The contributing factors in collisions that are tied to human aspects are also numerous. Driver impatience, familiarity with the railway crossing, distractions, risk-taking and an unawareness of danger are but some of the main human factors behind collisions between road vehicles and trains. In general, few drivers appear to be aware of the dangers presented by grade crossings. Even fewer drivers have had any kind of training on the attitude to take when crossing a railway track. This absence of the perception of danger and the lack of education compound each other and result in the fact that many drivers take risks when approaching railway crossings.

1.1 Responsible organizations

Many – primarily government – organizations in Canada and the United States are involved in maintaining safety at grade crossings. The sections below present an overview of the mandate and purpose of these various organizations.

1.1.1 Transport Canada

Transport Canada's mission is to develop and administer policies, regulations and services to establish and maintain the best possible transportation system for Canada and Canadians – one that is safe, efficient, affordable, integrated and environmentally friendly.

The Safety and Security Group of Transport Canada is responsible for the development of regulations and national standards, as well as for the implementation of monitoring, testing, inspections, research and development and subsidy programs, which contribute to safety and security in the road, marine, aviation and rail modes of transport used in Canada. Thus, many organizations or activities related to railway crossing safety are the responsibility of Transport Canada.

1.1.2 Transportation Development Centre (TDC)

TDC is the Transport Canada research and development (R&D) branch. This organization manages an R&D program covering all modes of transportation, including the transport of dangerous goods. On 13 May 2002, Canada and the United States signed a memorandum of co-operation on railway grade crossing research. This agreement allows Canada and the U.S. to exchange information, to benefit from each other's research and knowledge and to co-operate on specific research projects. TDC and the U.S. Federal Railway Administration (FRA) thus inform each other of ongoing and intended research in order to minimize duplication. TDC has been conducting a Highway-Railway Grade Crossing Research Program since 1999 as part of Direction 2006.

1.1.3 Direction 2006

Following an independent federal government review of the *Railway Safety Act* in 1994, the review committee recommended that collisions at grade crossings and railway trespassing incidents be reduced by 50 percent over a 10-year period. To meet this goal, the federal government introduced the Direction 2006 initiative in 1996 with the mission to eliminate all collisions and deaths related to grade crossings or trespassing on railway tracks. It is a partnership between railway stakeholders in the public and private sectors.

To reach its objective of halving the number of collisions, Direction 2006 identified a number of key areas of intervention: education, enforcement of the act, engineering, research, bureaucratic and legislative framework, resources and communications. The program plans to introduce, among other things, additional railway safety teaching elements in provincial driver training programs and vehicle driving manuals.

1.1.4 Operation Lifesaver

Operation Lifesaver is a national public education program. It is sponsored by the Railway Association of Canada and Transport Canada in co-operation with the Canada Safety Council, provincial safety councils and leagues, railway companies, police forces, unions and community groups.

This ongoing education program is aimed at increasing general public awareness of the dangers of grade crossings and encouraging drivers and pedestrians to be more aware of rail traffic.

1.1.5 Quebec Department of Transport (MTQ)

The Transportation Safety Policy (Road Component) aims to establish policy directions and priorities of the Quebec Department of Transport (MTQ) and the Société de l'assurance automobile du Québec (SAAQ) to reduce the number and seriousness of road collisions, while maintaining the mobility of persons and goods. The new transportation safety policy aims to improve the accident toll by 15 percent by the end of 2005.

Passed in June 1998, the *Act Respecting Owners and Operators of Heavy Vehicles* (commonly called Bill 430) introduces a new method of managing road use privileges. This tool is now in place to identify, and if necessary, penalize the users of heavy vehicles that are at risk or non-compliant.

1.1.6 Transportation Safety Board (TSB)

The mandate of the TSB is essentially to promote safety in transportation by ship, rail, air and pipeline. The main activities of this Canadian government agency are to conduct independent investigations into selected transportation accidents to determine their causes and contributing factors, to identify safety deficiencies, to make recommendations designed to eliminate or reduce such deficiencies, and to report publicly on its investigations and findings.

The main characteristic of the TSB is its independence. Its policy is to investigate only those accidents that may result in the formulation of a safety measure or that are in the greater public interest.

1.1.7 U.S. Federal Railroad Administration (FRA)

The FRA is a U.S. government agency whose purpose is to promulgate and enforce rail safety regulations, administer railroad assistance programs, conduct research and development in support of improved railroad safety and national rail transportation policy, and consolidate government support of rail transportation activities.

In addition, the FRA informs the public on rail crossing safety and the dangers of trespassing along railroad rights of way. The FRA’s ground transportation research and development program seeks to advance knowledge in the physical sciences and engineering in order to improve railroad safety and ensure that railroads continue to be a viable national transportation resource.

1.1.8 Federal Highway Administration (FHWA) – US Department of Transportation

The FHWA is part of the U.S. Department of Transportation. The FHWA provides expertise, resources and information to continually improve the quality of the American highway system and its intermodal connections.

The FHWA, together with the FRA, Operation Lifesaver and other organizations, has been very successful in improving safety at grade crossings. The FHWA is also very proactive in applying the recommendations of the National Transportation Safety Board in the U.S.

1.1.9 National Transportation Safety Board (NTSB)

The National Transportation Safety Board is an independent U.S. federal agency charged by Congress with investigating every civil aviation accident in the United States and significant accidents in the other modes of transportation, and issuing safety recommendations aimed at preventing future accidents. It is the U.S. equivalent of the Transportation Safety Board of Canada.

1.1.10 Volpe Center

The John A. Volpe National Transportation Systems Center in Cambridge, Massachusetts, is an internationally recognized centre of transportation and logistics expertise. Through research and development, engineering and analysis, the Volpe Center helps decision makers define problems and pursue solutions to lead transportation into the 21st century.

Recently, to promote the use of intelligent transportation systems at grade crossings, the Department of Transportation’s Joint Program Office initiated a research program on grade crossings. The Volpe Center is currently participating in this effort and specific initiatives focus on: extending the knowledge base related to collision statistics and international processes used at grade crossings, evaluating operational tests on prototypes and in the field, carrying out pilot projects, improving components, deploying new technologies, initiating activities aimed at developing new regulations, producing expert advice for states and municipalities in the deployment and evaluation of new devices, conducting comparative analysis studies and distributing research results.

Among its projects, the Volpe Center is currently conducting a simulation study on the impact between a rail car and a heavy vehicle to establish and improve the impact resistance of rail cars.

1.2 Collisions at grade crossings

In Canada, the number of collisions at grade crossings dropped by half between 1983 and 2000. Thus, from a strictly statistical aspect, the goal of Direction 2006 to reduce by half the number of accidents that occurred in 1996 will be reached by 2006.

Nevertheless, despite a constant decline in the number of collisions at grade crossings, the percentage of these collisions involving commercial vehicles is on the rise. As shown in Table 1, this percentage went from 13.9% in 1990 to 17.5% in 2000 (Tardif, L.-P., 2001).

Table 1 – Number of Collisions at Grade Crossings Between 1990 and 2000

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Total number of collisions	386	407	386	379	390	380	366	307	273	282	262
Number of collisions involving commercial vehicles	54	53	35	55	47	65	53	49	33	49	46
% of collisions with commercial vehicles	13.9	13.0	9.0	14.5	12.0	17.1	14.4	15.9	12.0	17.3	17.5

In the U.S., although heavy vehicles are involved in only 11% of road collisions, they are involved in more than 20% of the collisions occurring at grade crossings. Since these statistics date back to 1967 and the situation in the U.S. is relatively similar to Canada's, the percentage of heavy vehicles involved is likely to be even higher now (Harwood, et al., 1990).

The causes generally identified for these collisions are almost exclusively related to human factors. However, the predominance of these factors does not result from their greater influence on grade crossing safety, but rather from the predominance of studies focusing on this subject compared with those looking at the technical factors. Furthermore, through studies of past trends of accident causes, human factors are much easier to identify because the viewpoints expressed by the drivers after the accident in most cases refer to their reaction to the situation that provoked the collision. Finally, the technical factors related to grade crossing design are harder to identify because the drivers and interviewers do not know all the design standards or criteria that determine whether a grade crossing complies with the standard. Thus, identifying the technical factors that could contribute to a collision often requires a much more detailed analysis than those usually conducted. The investigations led by the TSB are one of the best sources for identifying these factors, and they are discussed in the next section.

In the U.S., the National Transportation Safety Board (NTSB) has conducted a number of studies to identify contributing factors in grade crossing accidents. One of the studies determined that in 75 accident cases studied, 52 were the result of driver attitude. Another study determined that in 60 accident cases studied, 49 were the result of driver attitude, with 13 collisions resulting from drivers failing to come to a mandatory stop, 16 due to the fact that drivers had failed to check whether a train was approaching, 10 attributed to driver distraction and 5 collisions resulting from an error in judgment on the part of the driver. In the 11 other cases, 7 accidents were due to visibility problems (Caird, J.K. et al., 2002).

A study conducted by Wigglesworth in 1979 on a sample of 85 crossing accidents determined that 73 of the drivers involved were familiar with the crossings. In 85 collision cases, 68% of the drivers used the crossing where the accident occurred at least 4 times per week and 19% of drivers used it 2 to 4 times per week (Caird, J.K. et al., 2002).

The results of a study by Knoblauch and Hucke conducted in 1981 also showed that most drivers who used a railway crossing after the lights started flashing did so in the 30 seconds following their activation (Caird, J.K. et al., 2002).

Studies by Lerner et al. in 1990 and the NTSB in 1998 showed that 81% of the collisions at crossings were due to recognition errors. These could be divided into two groups: a lack of recognition of the presence of a train, and a lack of recognition of the actions available to avoid a collision. Of these collisions, 19% were due to late recognition of a train. Furthermore, 18% of all collisions were due to errors in judgment. Nevertheless, most of these collisions were due to insufficient sight lines. At active crossings, the accident frequency was 10 times lower when gates were installed in addition to flashing lights (Caird, J.K. et al., 2002).

A study by Meeker et al. in 1997 showed that 67% of drivers still crossed when the lights were activated and 38% still crossed after the gates had started to lower or were even completely down (Caird, J.K. et al., 2002).

Berg demonstrated in 1988 that the risk of an accident is seven times higher when the road is parallel to the tracks and the train is approaching from behind the driver's field of vision (Caird, J.K. et al., 2002).

Furthermore, to evaluate the safety of a particular crossing statistically, comparing only the number of collisions at the given crossing with other crossings is not meaningful; the number of accidents has to be put into perspective against the exposure rate at the crossing, meaning that this number has to be a function of the volume of road and rail traffic. The index that should be used for this type of analysis is the cross product, meaning the product of the average daily number of vehicles and trains that use the grade crossing (Caird, J.K. et al., 2002).

Abraham et al. (1998) remarked that 56% of collisions occurred at active grade crossings, even though 80% of the grade crossings in Canada are passive. This can be explained by the fact that these crossings are used much more frequently than passive grade crossings. By comparing the number of accidents to the product of grade crossings, it can be seen that active grade crossings are much safer than passive ones. It was determined that the number of accidents fell by 70% at active crossings when gates were installed, and that there was an even greater reduction in rural areas (Caird, J.K. et al., 2002).

Caird (2002), who studied the Rail Occurrence Database System (RODS), determined that more than 50% of the collisions occurred at grade crossings with angles of less than 80^o or more than 100^o. He was also able to determine that 40% of collisions occurred between 9:30 am and 3:30 pm and that 35% of them occurred in rush hour. He also noted that the majority of collisions (proportional to the number of days) occurred during the week and that January and December were the months with the highest collision rates while April was the month with the lowest.

The same author conducted several searches in RODS. He started with quantitative research with respect to the types of accidents and related unsafe conditions: research was done for various types of unsafe acts, different road conditions, and different conditions of the driver involved. The results of this research are presented in tables 2, 3 and 4 below. In Table 2, an intentional act is one that is done for a specific reason, such as trying to cross faster than the train, while an unintentional act is the result of an error in judgment.

Caird then did a qualitative analysis of the accident descriptions in RODS. He divided the accident causes into three categories: collisions due to intentional acts, collisions due to distractions, and collisions due to visibility problems. Without going into detail, Table 5 presents the main causes of the collisions he studied.

Richards & Heathington (1996) found that 20% of drivers thought that all crossings were active and interpreted the absence of signal lights as an absence of trains. This study is several years old, but all indications suggest that the situation has not improved in this respect (Caird, J.K. et al., 2002).

Table 2 – Unsafe and Intentional Acts from 1999 to 2000 (Caird, J.K. et al., 2002)

Crossing type	**Unknown**	**Intentional**	**Unintentional**	**Total**	**%**
Failed to stop	162	107	161	430	70.6
Skidded onto track	7	6	29	42	6.9
Stopped too close	4	9	13	26	4.3
Stuck on track	7	1	18	26	4.3
Stalled on track	1	6	18	25	4.1
Drove around gates	1	21	2	24	3.9
Stopped then proceeded	4	-	7	11	1.8
Drove through gates	1	8	1	10	1.6
Vehicle pushed onto track	1	1	3	5	0.8
Drove into second train	-	-	1	1	0.2
Total	**187**	**169**	**253**	**609**	**100.0**

Table 3 – Unsafe and Unintentional Acts from 1999 to 2000 (Caird, J.K. et al., 2002)

Condition	**1998**	**1999**	**2000**	**2001**	**Total**
Snow covered	2	5	4	3	14
Icy	4	2	-	-	6
Fog	1	2	1	1	5
Rain	-	2	2	-	4
Wet	2	-	-	1	3
Sun glare	1	1	-	-	2
Night	-	1	1	-	2
Wind	-	-	1	-	1
Dusk	-	1	-	-	1
Total	**10**	**14**	**9**	**5**	**38**

Table 4 – Unsafe Internal Conditions from 1998 to 2001 (Caird, J.K. et al., 2002)

Condition	**1998**	**1999**	**2000**	**2001**	**Total**
Attitudes	115	28	22	24	189
Attention/Vigilance	4	60	30	13	107
Information processing	13	21	14	2	50
Mental/emotional state	6	9	4	3	22
Alcohol	3	9	3	1	16
Planning	1	6	1	1	9
Handicap	-	2	-	-	2
Vision limitations	-	2	-	-	2
Experience/recency	-	1	-	-	1
Total	**142**	**138**	**74**	**44**	**398**

Table 5 – Analysis of Accident Descriptions in RODS (Caird, 2002)

Category	**# of cases**	**Cause**
Intentional acts	35 cases	Drove around gates
	16 cases	Attempted to beat the train
	10 cases	Stopped, then proceeded
	10 cases	Drove around stopped vehicles
	5 cases	Impaired driving
	4 cases	Drove around stopped vehicles and gates
	3 cases	Slowed, then proceeded
	3 cases	Fatigue
Distractions	12 cases	Did not see train and/or signals (many causes for distractions)
	9 cases	Saw train too late to stop; 8 cases were at passive crossings
	7 cases	Talking on cellular phone or radio
	4 cases	Internal distraction; cognitive process, preoccupied, mental state, inattention
	3 cases	Talking with passengers; noisy children in the back
	3 cases	External distractions: watching other vehicles
	1 case	Adjusting radio dials
		Multiple causes were also reported
Visibility problems	25 cases	Fog: was driving too fast for visibility conditions, reduced visibility of the road and train's approach, did not see the automatic warning system or the advance warning signs.
	21 cases	Sun: rising or setting sun, glare off road or windshield.
	10 cases	Obstructed sightlines: distance, angle, curvature, vegetation, buildings, snow bank, lines too short, object in vehicle, stopped or parked vehicle obstructed the sightlines.
	4 cases	Snow: blowing snow, storm, no reduction of speed in these conditions.

1.2.1 TSB collision occurrence reports

We were able to identify eight occurrence reports published by the Transportation Safety Board (TSB) since 1994 that dealt with collisions between a train and a heavy vehicle. The results of these investigations are presented below as examples of real cases of collisions at crossings. All the reports mentioned are available in their full version on the TSB's Internet site.

Report R94C0035

On 30 March 1994, a Canadian Pacific train was passing over the public crossing in Crowsnest Trail, Alberta when the leading car was struck by a loaded eastbound dump truck, killing the truck driver, destroying the truck, derailing the leading car, damaging a building and injuring the yard foreman. The crossing was a very busy, active crossing (18,000 vehicles and three or four trains per day), the warning signals were operating at the time of the accident, and the advance warning signals were present 150 m before the crossing. Upon a detailed analysis of the collision, the inspectors were able to determine that the truck's braking system had serious mechanical problems that prevented the truck from stopping before the crossing. Because the cause of this accident was essentially due to the truck's mechanical problems, the Board did not make any safety recommendations, since this problem fell under provincial jurisdiction. Some concerns were nevertheless expressed regarding the standards in some provinces governing heavy vehicle braking capacity. Many of these standards have been amended since.

Report R94D0191

On 4 November 1994, at approximately 8:12 p.m., a VIA Rail train collided with a tractor-trailer at a public crossing in the municipality of Rivière-Beaudette, Quebec. The driver of the vehicle had slowed as he approached the tracks because a westward freight train was just clearing the crossing. The automatic warning devices deactivated, the vehicle entered the crossing, the warning devices immediately reactivated to warn of an approaching passenger train, and the truck driver abandoned his moving vehicle to run to safety. Upon impact, the leading truck of the locomotive derailed, the fuel tank punctured, and a fire erupted at the rear of the locomotive. The locomotive and second car were extensively damaged, three coaches sustained minor damage, the tractor-trailer was completely demolished, and two passengers and two locomotive engineers sustained minor injuries. The TSB Engineering Branch conducted several acceleration tests at this crossing with a similar vehicle. Not knowing the position and exact speed of the truck, several possibilities were examined. It was determined that in the majority of cases, the vehicle would not have been able to cross the tracks in time if the driver had stayed at the wheel. According to Transport Canada, the driver had not intentionally put his life in danger. It is held that in some cases, truck drivers approaching a crossing could find themselves in a situation where they cannot stop in time nor accelerate to cross the rail tracks safely. In addition, the truck was climbing a grade of over 2% when crossing the tracks. The TSB thus concluded that the warning devices functioned as intended, but that the truck driver either did not correctly interpret the situation in time to avert the collision or he was unable to do so. The Board was concerned about situations that could create a "no option zone" for heavy vehicles. It was at this time that Transport Canada initiated the RTD 10 project.

Report R94M0100

On 14 December 1994, at approximately 1 p.m., a trailer loaded with wood chips became unhitched from its tractor on the public crossing at Mont-Joli, Quebec. A westward CN train struck the trailer, derailing the locomotive and several cars. The derailed train continued on, damaging the bridge over the Matapédia River, resulting in the trailing locomotive and nine cars falling onto the riverbank. No one was injured. The road made a 90-degree turn just before the crossing. After examining the events, the Board determined that the accident was due to poor inspection before departure of the fifth wheel of the trailer, which separated from the tractor while making a 90-degree turn to access the crossing. Several other discrepancies were noted with respect to the work of the rail traffic controller, who did not take the mileage point out of service when informed of the collision. Following this occurrence, CN evaluated several factors regarding the rail traffic controller's workload, reorganized and redistributed the rail traffic controller territory, and provided supplemental training to the controller in question.

Report R94V0206

On 22 September 1994, in Fort Langley, British Columbia, a CN freight train proceeding eastward struck a southbound commercial garbage truck at a public crossing. The driver and a passenger in the truck were killed. The police investigation revealed that the length of the skid marks indicated that the speed of the truck was such that it could not have stopped at the stop sign before the crossing. The sight line in the northwest quadrant of the crossing was obstructed by large trees on private property. It was also determined that the position of the sun may have impaired the driver's ability to see. Furthermore, the Board also commented that at the time no statutory provisions were available to force the removal of bush or trees on private property that were a hazard at crossings. In February 1996, active warning signals and gates were installed at this crossing. It also commented that the *Railway Safety Act* allowed Transport Canada to enforce regulations requiring the removal of trees or bush on private property, even though the regulations had not yet been promulgated. The Board also suggested that Transport Canada apply the regulation, even though it is aware that this process can be time consuming.

Report R95D0081

On 6 June 1995, at approximately 1:50 p.m., a CN freight train struck a tractor-trailer near Saint-Léonard, Quebec. One member of the crew was killed. As the train approached the crossing, the trainman observed a tractor-trailer approaching the crossing. The trainman made hand gestures to tell the driver to stop, but the driver interpreted them as permission to proceed. In these circumstances, the train should have stopped and a flagman should have been posted during the passage of the train. Subsequent to this occurrence, CN issued a circular emphasizing the proper application of this rule.

Report R99H0009

On 14 July 1999, near Horepayne, Ontario, a VIA Rail train collided with a tractor-trailer at a private crossing used primarily by lumber trucks. As a result of the collision, the truck spun and struck the side of the train causing three locomotives and eight passenger cars to derail. Two fuel tanks were sliced open and their contents fuelled two small fires. Three people were seriously injured and a total of eight people were taken to the hospital. The cost of the material damages was also very high. The empty tractor-trailer maintained a low rate of speed because the road and crossing were rough. There was a stop sign approximately 3 m before the crossing. As the driver was approaching the crossing, the train whistle sounded but the driver did not hear it because he was listening to music at a high volume in the cab. The regional engineer concluded and reported that the crossing was in compliance with all existing guidelines and regulations. However, Guideline G4-A (Minimum Railway/Road Crossing Sightline Requirements for all Grade Crossings without Automatic Warning Devices) required a minimum sight line of 413 m for a crossing with a maximum train speed of 60 mph and a stop sign that is used by heavy vehicles. Despite the guideline, the sight line in the direction of the train was only 365 m. The Transport Canada Regional Engineer's study determined that 25 seconds were needed to offer a safe passage at a crossing where heavy vehicles travel. With this crossing time and a train speed of 60 mph, a sight line of 686 m would have been necessary. The Board concluded that the cause of the accident was due to the fact that the truck driver did not see the approaching train and did not hear the train whistle because of the noise inside the truck cab. The Board also established that given the visual cues and the presence of a stop sign, it is likely that the driver would have been able to see the train had he stopped at the stop sign and looked down the track. Nevertheless, although they were not the direct causes, the Board also listed certain risk factors such as using guidelines that do not provide enough time for a tractor-trailer to safely cross over a crossing. Since the accident, Transport Canada has revised the RTD 10 standard.

Report R99T0298

On 23 November 1999, a Canadian National train struck an abandoned tractor-trailer at a farm level crossing in Bowmanville, Ontario. The train derailed after dragging the trailer for approximately 2,000 feet along the track. Then an oncoming Via Rail train on the adjacent track struck the debris and also derailed before the first train came to a halt. In the accident, minor injuries were sustained by six VIA Rail employees and five passengers. The tractor was pulling a flatbed loaded with machinery. The crossing did not comply with public crossing standards with respect to the grades on the approach, which were actually 6% up hill. However, because it was a farm crossing, the standards were less strictly applied. The heavy vehicle had become stuck on the tracks and the driver could not free it, but he made no emergency call, even after the derailment. Other than the fact that the tractor-trailer was stuck on the rails, the Board stated that one of the causes of the accident was that the crossing surface was poorly constructed and maintained because the rear wheels of the tractor-trailer broke through wooden ties covering a ditch on the approach. Another cause was the driver's ignorance of the emergency communication tools available. This crossing was subsequently closed because it was deemed too dangerous.

Report R00C0159

On 19 December 2000, at approximately 8:37 p.m., the 21st car of an Athabasca Northern Railway Ltd. freight train was struck by a tractor-trailer at a crossing in Imperial Mills in Alberta, causing the train's emergency brakes to activate automatically. At 11:47 p.m., while the train was still on the crossing, a truck partially loaded with logs collided with the stopped freight train, killing the driver. The driver of the first truck did not see that the train's wheels were moving on the rails until 200 m before the crossing. He tried to stop but when he realized that he would not be able to stop in time, he turned into the ditch but still struck the train. Before seeing the train, the driver said that he had been distracted by the reflection in his mirrors of the lights of the truck following him. The death of the second driver made it more difficult to determine the causes of the accident, but the speed of the impact, estimated at 68 km/h, strongly suggests that the driver did not see the train. At the time of the second impact, the truck that was used to move the first tractor-trailer was the only vehicle remaining after the first accident. It was stopped on the right side of the road with its flashers on, and the truck with the wood drove around this vehicle before striking the train. According to the Board, in both cases the train was not sufficiently visible to be seen within a reasonable time, especially in the second case because the immobility of the train made it even harder to see. The Board also determined that the poor reflectivity of the train combined with the passive nature of the crossing and the high speed limit represented a very high accident risk. Lakeland County, where the accident occurred, asked the Alberta Ministry of Transport to install an active warning system, but the request was denied because of the low volume of traffic.

1.2.2 Technical contributing factors related to configuration and design

The technical factors that affect safety at crossings are mostly ones resulting directly from a poor design, poor maintenance or the use of unsafe design and inspection standards.

From a strictly technical point of view, the sightlines on the approaches to crossings and the warning times ensure the safety of the crossing. Excluding all human error or dangerous behaviour, the warning times and sightlines enable the driver of any vehicle travelling normally along the road where the crossing is located to assure him or herself that no train is approaching the crossing and that it can be crossed safely, or that there is enough distance to stop if a train is coming. Nevertheless, these sightlines and warning times are often inadequate and can create dangerous situations over which drivers have no control, especially in the case of long and heavy vehicles (Coghlan, M., 1997).

The sightlines and warning times should be based on the worst performances in terms of crossing times and braking distance of the vehicles that use the road where the crossing is located. However, the specifications of the vehicles presently used to determine these sightlines and warning times are no longer up to date and thus no longer necessarily represent the real specifications of vehicles currently using our roads (Caird, 2002 and Harwood, 1990).

Also, for economic reasons, the minimum values often become the standard. For instance, the results of tests (acceleration and braking) conducted in ideal conditions are in some cases used as the design standards when in reality these ideal conditions are far from the usual conditions at the crossing. Instead, these standards should serve as guidelines, and factors that depart from ideal conditions should be considered in developing design standards. The combination of this situation and ambiguous standards whose various remedies are poorly understood and poorly defined can often lead to the use of minimum standards. This situation should be corrected by applying simpler standards that are better adapted and more clearly explained (Caird, 2002 and Coghlan, M., 1997).

1.2.2.1 Sight line for stopped vehicles

The sight line when stopped is the line measured along the railway tracks for a vehicle initially at a stop. Often, this sight line is based on a minimum crossing time of 10 seconds, which is still recommended by the Draft RDT 10, although many studies have shown that this crossing time is insufficient for grade crossings with more than one track and for long and heavy vehicles. Similarly, the warning time at active crossings is often based on a minimum crossing time of 20 seconds, also still recommended in the draft RTD 10, despite the fact that many studies have shown that this time is often insufficient (Coghlan, 1997 and Read, 1995).

Crossing times are often based on the results of tests conducted on mostly level terrain and in ideal conditions. These results are not conservative enough because many factors affect a vehicle's crossing time, such as the presence of grades and banking, the poor quality of the crossing surface, and the difference in height between the rails and the crossing surface. The poor state of the crossing surface, observed at many crossings, discourages drivers from accelerating fully when crossing so as not to damage their vehicle or feel discomfort. Determining the crossing time should thus include a safety margin that takes the effect of an eventual degradation in the crossing surface into account (Coghlan, 1997).

The presence of an intersection after a crossing also affects the crossing time of vehicles. An intersection cannot be located less than 30 m from a crossing, but a number of crossings do not comply with this rule. In addition, any intersection close to a railway has an impact on the crossing time of long vehicles, such as B-train doubles. In fact, the presence of an intersection obliges drivers of such vehicles to start braking or stop accelerating before their vehicles have even completely cleared the crossing (Caird, 2002). This increases the crossing time and must be taken into account. Furthermore, if an intersection is too close to the railway tracks, long vehicles such as B-train doubles, could be obliged to stop partly on the tracks if they have to stop at the intersection. Using traffic lights that are synchronized with the train warning system could help remedy this problem by allowing vehicles to clear the crossing before a train arrives.

In addition, various provincial regulations make stops mandatory and prohibit certain vehicles from changing gears when crossing railway tracks. These regulations are presented in section 1.3.4. They have a direct impact on vehicle crossing time and should therefore be taken into account when calculating the crossing time. In other cases, a mandatory stop makes it possible to ensure the safety of a crossing where the sight triangle cannot be completely cleared. In addition, a ban on changing gears greatly increases the crossing time for most heavy vehicles. Originally, the regulation prohibiting drivers from changing gears was designed to keep certain vehicles from getting stuck on the tracks if drivers missed the gear, and it was felt that this method was faster for short crossings. This no longer applies to heavy vehicles today, which are equipped with much more reliable transmissions than in the past, which almost eliminates the risk that the transmission will get stuck. Since transmissions have many more speed ratios than in the past, acceleration is much faster over short distances when shifting gears.

Another aspect that is worth considering is that although a crossing is designed according to the criteria of a certain type of vehicle that represents the worst performance of most of the traffic using the crossing, it sometimes happens that crossings are used by vehicles with even poorer acceleration and braking performance than the type of vehicle used for the design. This can create a dangerous situation if such a vehicle crosses at the wrong time. Nevertheless, since this situation tends to be rare, it is up to the road and rail authorities to evaluate the risk and determine whether it is reasonable. It would be much too costly to design a crossing for the worst possible vehicle that might ever use it. A risk analysis should thus be done to evaluate which type of vehicle is best to use when designing crossings (Coghlan, 1997).

1.2.2.2 Sight line for vehicles travelling at the legal speed limit

The stopping sight distance determines the sight triangle when there is no mandatory stop at the crossing, as well as the warning time for active crossings. The stopping sight distance is the distance along the road from which drivers should see the crossing before reaching it; for a passive crossing, it is the distance along the road that drivers should be able to see an approaching train. These distances should be such that drivers can brake when they see a train, but should also allow them to cross the tracks safely if they cannot. This stopping sight distance should be based on the longest braking distance of all the vehicles using the crossing in question. However, the braking distances currently used in the design standards are based on braking tests conducted more than 50 years ago on automobiles with locked wheels. We believe that the braking distances for heavy vehicles should be used rather than those for automobiles, and that these vehicles cannot brake safely with locked wheels because of their lack of stability. Some studies have also shown that the values used in the standards are lower than the real braking distances of heavy vehicles, the only exceptions being the braking distances of heavy vehicles equipped with ABS systems. Because not all heavy vehicles are equipped with full ABS systems, and drivers are not necessarily able to take advantage of the full braking capability of their vehicle depending on their experience and skill, it would be better to take these factors into consideration. Thus, everything leads us to believe that the distances currently used to determine the stopping sight distances are not safe (Harwood et al., 1990).

Furthermore, the current method of calculating the sight triangle based on the legal speed limit could make a crossing unsafe for vehicles whose speed deviates from this limit. If vehicles exceed the limit, the drivers will probably not have enough distance to stop if they see a train. If a vehicle is travelling slower than the speed limit, which is not uncommon because many drivers tend to slow down when approaching a crossing (Coghlan, 1997), and the driver has not seen any trains approaching, there is still a chance that a train could reach the crossing before the road vehicle. To solve this problem, a safety factor should be used, which is not currently the case.

1.2.2.3 Maintaining sightlines

Maintaining sightlines is an important factor. In many cases, it is not the original sightlines that are inadequate but rather their maintenance, because vegetation has grown and reduced the lines established when the crossings were designed. The sightlines must be maintained regularly by the authorities responsible for them and no building or pile of debris, equipment or materials should be placed in the way (Read, J.A., 1995).

Furthermore, even if sightlines are well designed and maintained, many drivers generally do not know where they start and end on the road and tracks. This ignorance could lead to driver judgment errors. For instance, in a field where the sightlines are much longer than necessary, drivers could think that they have time to cross when they do not. To remedy this shortcoming, warning signs could be placed at the ends of the sightlines to allow drivers to make a safe decision (Read, J.A., 1995).

1.2.2.4 Communication problems and other technical factors

Communication problems can also affect safety at crossings. The poor exchange of information between municipal and rail authorities can create certain problems. When the rail authorities do not have an accurate estimate of the composition of traffic, which is the responsibility of municipal authorities, the choice of vehicle type for the design of the crossing may not be adequate. Furthermore, if maintenance responsibilities are poorly defined, sightlines may not be cleared regularly, creating a dangerous situation. The same goes for the sharing of road maintenance responsibilities, since at a crossing with more than one track, the crossing surface between the rails of a single track and the surface just around them are the responsibility of the rail authorities, while the road surface between the tracks is the responsibility of the municipality. If these two authorities do not work together, the maintenance and repair of surfaces may be done at different times and could result in a surface that is never in good condition.

Other technical factors that are not directly related to the sightlines can also affect the safety of crossings. They include advance warning signs that indicate a crossing is ahead but that do not say whether it is active or passive, which does not give drivers an indication of what they should do. For an active crossing, drivers must simply ensure that the lights are not flashing when they cross, while at a passive crossing, they must look for the presence of a train. Since 20% of drivers do not know that passive crossings exist, it is possible that they may interpret the absence of signals as an absence of trains (Caird, J.K., 2002).

A cause of collisions specific to multi-track crossings is the passing of a second train right after the first one. The drivers of vehicles stopped at one of these crossings could decide to cross the tracks as soon as the first train has passed, even though a second train, hidden by the first, is coming from the other direction. In the case of active crossings, many studies have suggested using signs that light up when a second train is approaching, whereas at passive crossings, only a sign indicating the potential arrival of a second train could be used. It should be noted however that passive multi-track crossings are very rare.

Statistics on the causes of accidents have also revealed that the risk of collision at a crossing is seven times higher when the road is parallel to the tracks and road vehicles are travelling in the same direction as the train. The drivers of vehicles approaching a crossing could have trouble seeing a train that is coming from behind them. Changing the road so that it crosses the tracks at 90 degrees, and installing a mandatory stop would greatly reduce this accident risk (Caird, J.K., 2002).

Finally, the circumstances of some accidents indicate that vehicles stop between the protective gates because the time it takes for the gates to lower is not properly calibrated. Thus, the calculation for the gate descent time and the time between the activation of the lights and when the gates start to lower should be reviewed (Coghlan, M., 1997).

1.2.3 Human contributing factors

As mentioned above, human factors are often one of the main causes of collisions at grade crossings. Most of these factors can be grouped into three categories: risk taking, inattention and unintentionally unsafe behaviour.

1.2.3.1 Risk taking

Behaviour that is common among many drivers is a rolling stop. By not coming to a complete stop, drivers have less time to notice the approach of a train. In addition, checking for a train while the vehicle is still moving can make the remaining distance too short to be able to stop (Coghlan, M., 1997).

According to Caird, another form of unsafe behaviour due to risk taking is the failure to come to a mandatory stop at a crossing. Not all crossings have a mandatory stop, and when they do not, it is safer to continue driving at the posted speed limit. However, when a mandatory stop exists, it is normally safer to stop. In fact, a mandatory stop exists because it is impossible to clear a sufficient sight triangle or for other similar reasons. At such crossings, failure to come to a mandatory stop can prevent drivers of vehicles from seeing an approaching train in time to stop their vehicle before the tracks.

Failure to visually check for the approach of a train is another type of intentional unsafe behaviour. This behaviour can be due to several factors and is not necessarily intentional. Many drivers think that all crossings are active and therefore not checking for a train is a natural behaviour because they think that a system will warn them of an approaching train, even if the crossing is passive.

Statistics also show that many accidents were due to drivers who tried to beat the train, i.e., they tried to cross first, probably in order to avoid stopping at the crossing. Another form of risky behaviour is trying to cross even if the flashing lights have been activated or the gates have started to lower. Many factors could be behind these two causes of accidents, but driver impatience is no doubt the primary factor that leads them to behave this way. In fact, impatience is recognized as one of the basic reasons for many collisions, whether they occur on the road in general or at crossings.

Another cause of collisions at crossings identified by Wigglesworth (1979) is familiarity with the crossing. This familiarity is a risk factor behind many types of dangerous behaviour that are often the cause of collisions. One risky behaviour identified is assuming that the train schedule is always the same: when drivers are very familiar with a crossing, they eventually become very familiar with the train schedule as well. When they use a crossing at a time when they think there is no train, they tend to ignore the necessary precautions when approaching a crossing and make less of an effort to check whether a train is approaching. However, trains are not always on time and drivers can find themselves in a potential collision situation (Caird, J.K., 2002).

Another form of dangerous behaviour that can also be caused by familiarity with the crossing is a loss of faith in the warning system if it is designed for a type of vehicle with much poorer performance than the vehicle of the driver in question (for instance, a motorist using a crossing designed for a B truck-train). Because the warning time is much longer than what drivers perceive as necessary, they become impatient, lose faith in the warning system and, eventually, decide to cross even when the lights are flashing. This situation should be examined in more detail, because it was determined that after 30 seconds of warning without the arrival of a train, many motorists become impatient and decide to cross. Many crossings are designed with a warning time of 30 seconds or more because long and heavy vehicles use them often and long warning times are the only way to ensure the safety of the crossing. To reduce dangerous behaviour related to impatience caused by long warning times while maintaining the safety for long and heavy vehicles, the installation of gates could probably be recommended in some cases.

Impaired driving is another risk behaviour that causes many collisions. Impaired driving can be due to various reasons, such as fatigue, alcohol, drugs or medication. This behaviour can be even more dangerous at crossings because other vehicles on the road can in some cases react to impaired drivers and avoid them if necessary, but a train cannot stop nor attempt to avoid a road vehicle (Caird, J.K., 2002).

1.2.3.2 Inattention

Driver inattention is also a major cause of collisions at crossings. The inattention is not usually intentional behaviour resulting from risk taking, but can nonetheless be due to various situations or unsafe behaviour. Inattention can cause drivers to fail to check for an approaching train, not notice a crossing or not see it until it is too late to react in time. This driver inattention in most cases is due to some distraction that has the driver's attention.

Many types of distractions that were behind collisions at crossings have been identified. One of them, which could also be the cause of many collisions on the road in general, is the use of cellular phones while driving. This unsafe behaviour can cause considerable distraction for drivers, who can be concentrating on the discussion on the phone, can turn their attention from the road when the telephone rings, and who use one hand to drive while their other hand holds the phone. With the proliferation of cell phones, this behaviour is increasingly common and produces more risky behaviour (Caird, J.K., 2002 and Peters, G.A. et al., 2002).

Like cellular telephones, passengers can also be a source of distraction for drivers. The presence of noisy children in the back of a vehicle can also be a major source of distraction for drivers whose attention and eyes can often be diverted to calm the children. Another distraction identified as a cause of collisions at crossings is adjusting the controls for the radio or heat/air conditioning. At this moment, the attention of drivers is more on the controls on the dashboard and their eyes often leave the road (Caird, J.K., 2002).

Mental state is another factor that can cause driver inattention. Very deep thinking can sometimes require almost all of a driver's attention, and the attention paid to the road and the presence of a train is then limited. This mental state can result from a cognitive process, soul-searching or intense emotion. Several cases of collisions were reported where the mental state was behind the collision.

Caird also maintains that an intersection near a crossing can affect driver attention. The presence of an intersection, especially if it is very busy, can cause drivers to concentrate on the intersection rather than check whether a train is approaching the crossing.

1.2.3.3 Unintentional unsafe behaviour

A few other forms of dangerous behaviour behind collisions at crossings have been identified. However, although these actions are unsafe, they are often unconscious or unintentional. Generally, this behaviour is due to driver ignorance of crossings and their dangers. For instance, drivers tend to slow down to properly check both directions at a crossing because they think they will have more time to stop if they see a train, or simply because they want a smoother ride as they cross. While slowing down may seem safe, it can often be dangerous. Crossings are designed for vehicles travelling at the legal speed limit and slowing down could result in a vehicle no longer having enough room to stop or not having enough time to cross (Caird, J.K., 2002 and Read, J.A., 1995).

Similarly, some people treat flashing lights at crossings like other flashing lights on the road, i.e., like mandatory stops when in fact the flashing lights at crossings are the same as a steady red light. This incorrect interpretation of the role of warning lights at crossings can easily lead to a collision, because in many cases, these warning lights are installed because it is not possible to see a train soon enough to react at this spot (Caird, J.K., 2002).

In fact, most users of crossings do not know that sightlines and warning times are based on minimum crossing times, and this can lead to various other types of unintentionally dangerous behaviour (Caird, J.K., 2002 and Coghlan, M., 1997).

1.2.3.4 Other factors

Several other human factors that can also be a cause or contributing factor in a collision at a crossing were not classified in the three categories above. Some that were discussed in the literature are presented below.

First, one factor, identified by Caird, is the lack of recognition of the presence of a train when using a crossing. This lack of recognition can be due to some sort of distraction, a lack of judgment or insufficient or obstructed sightlines. As has already been mentioned, accidents are rarely due to a single, unique reason, but rather to a set of contributing factors. This is especially true for this human factor. While not recognizing a train in time is the direct cause of a collision, this lack of recognition is often due to another human or technical factor. Clearly, late recognition of a train is a very similar factor.

Caird also notes that identification of the presence of a train by a driver when approaching a crossing does not always mean that the collision can be avoided. Clearly, besides the various technical factors that could lead to a collision, there is also the possibility that a driver is not able to identify the actions required to avoid a collision. For instance, if a driver is preparing to cross at a passive crossing and at some point between the tracks and the stopping sight distance the driver sees a train approaching the crossing, instead of continuing safely across the tracks (assuming the crossing is properly designed), the driver may have the reflex to brake when there might not be enough distance to do so before the tracks. The opposite situation could also arise, where a driver may think there is still time to cross when the safe reflex would be to brake. This factor is due primarily to a lack of driver education regarding actions to take when using a crossing.

A last factor, which is partly due to poor crossing design, is the reduced visibility of trains when the road crossing the tracks is parallel to the tracks just before the crossing and trains approach from behind the driver’s field of vision. Berg (1981) demonstrated that the risk of an accident is seven times higher. Although one might think that this is merely a technical factor, it is also a human one because if the sightlines are properly cleared, drivers should be able to see the approaching train if they turn their head enough. However, this last aspect could cause a problem, because drivers very rarely check behind them (except to check their rear-view mirror or blind spot) in the back area of their blind spot where a train might be seen.

1.2.4 Environmental and circumstantial contributing factors

Environmental and circumstantial contributing factors are generally those that can affect the visibility of trains.

First, as in many road accidents, weather can be an important factor in an accident. Ice could make the surface slippery, thereby increasing braking distances and reducing the maximum acceleration that vehicles can reach. Since it would be much too expensive and sometimes even less safe to design crossings for icy road conditions, this situation can present a danger, especially for vehicles whose performance is similar to the crossing design vehicle. The stopping sight distances and acceleration times for these vehicles can then become longer than those used for the crossing design. Furthermore, weather conditions such as snow, heavy rain, fog or blowing snow can affect the visibility of trains at crossings, especially at passive crossings. Sun reflection has also been identified as a cause of accidents. Particularly at sunrise or sunset, the sun can blind drivers when they try to check for an approaching train. At other times of the day, the sun can reflect off windshields, which can also reduce visibility. Finally, a poorly parked vehicle or a snow bank piled up at a poor location can also obstruct sightlines. This has already been recorded as the cause of accidents in the past (Caird, J.K., 2002).

1.3 Current regulations

Before 1980, Canadian grade crossings had to comply with the design and inspection standards set out in General Order E-4 issued by the former Canadian Transport Commission (CTC). This order was superseded by CTC 1980-8 RAIL in 1980, which was subsequently amended in 1985. The order set out the procedures to follow when building crossings, the specifications that plans had to meet and some minimum standards governing the quality of the crossing surface, approach gradients and signalling. According to the *Railway Safety Act*, this order is still in effect.

However, given the lack of precision of the design and inspection standards for grade crossings, Transport Canada initiated a major project to improve and update its grade crossing regulations many years ago. A new draft regulation, RTD 10, aims to establish grade crossing design and maintenance standards that are much more comprehensive than existing regulations. Although it is not official or final, the latest version [*Draft RTD 10 – Road/Railway Grade Crossings: Technical Standards and Inspections, Testing and Maintenance Requirements* (that accompanies the *Grade Crossing Regulation*)] dated 14 June 2002 is nevertheless being used for designing grade crossings. When the final version is submitted, this document will be cited as a reference in the *Railway Safety Act* that governs all Canadian railway activities. In the meanwhile, the Assistant Clerk of the Privy Council of Transport Canada has introduced RTD 10 as a reference, but this amendment is not yet in effect. Before being officially adopted, a next version of RTD 10 will take studies being conducted into account, particularly this study on the impact of heavy vehicles on railway crossing safety. Since this draft has a major impact on the safety of grade crossings, it is discussed in detail in section 1.3.3.

Many acts, regulations and standards have a direct impact on the safety of grade crossings, especially those used by heavy vehicles. In particular, there are the *Geometric Design Guide for Canadian Roads* published by the Transportation Association of Canada, the *Vehicle Load and Size Limits Guide* issued by Transport Quebec, RDT10, and certain provisions in the highway codes for the various Canadian provinces. The following sections provide an overview of them.

1.3.1 Geometric design standards for Canadian roads

The Transportation Association of Canada publishes the *Geometric Design Guide for Canadian Roads* that sets out standards to use in the design of various aspects of Canadian road construction, particularly grade crossings. The design standards in RTD 10 are almost entirely based on this guide, especially with respect to the standards governing the maximum approach gradients at crossings and the braking distances and acceleration curves for different types of vehicles.

The role of design standards is to provide designers with information to allow them to choose the appropriate combination of criteria and dimensions for a specific design. However, it is important to realize that the design standards cannot cover all the conditions of a specific site. Thus, design dimensions that do not meet the standards do not necessarily result in an unacceptable design, and dimensions that do meet standards do not necessarily guarantee a safe design. All designs must be made with judgment. In addition, the standards are often based on the current and anticipated criteria and sizes of vehicles, on the behaviour and performance of drivers and on current technology. Since these criteria vary over time, the standards must be reviewed and updated periodically.

1.3.1.1 Grade crossings

The grade crossing design standards presented in the *Geometric Design Guide for Canadian Roads* are almost all included in RTD 10 and will be discussed below. However, the standard covering the difference in gradients allowed between the crossing surface and the road approaches is not included in RDT10. Since this standard can affect tractor-trailer vehicles with a dropped chassis frame (or Low-Boy) when using a crossing, we believe it should be included in RTD 10 to deal with the problem faced by this type of vehicle at grade crossings. The standard states:

"At all vehicular crossings of superelevated track, the profile of the roadway approaches should incorporate suitable vertical curves to match the plane of the crossing surface and to accommodate the maximum allowable roadway speed. Any departure from this practice might cause vehicle occupants to experience discomfort. Such discomfort, however, will not be objectionable if the values shown in Table 6 (Table 2.1.13.1) for the difference between roadway gradient and rail cross-slope are not exceeded. However, in the case of multiple crossings, the value should be well below the values shown."

Table 6 (Table 2.3.13.1 of the *Geometric Design Guide*) –
Allowable Difference Between Roadway Gradient and Railway Cross-Slope

Classification	Allowable Difference in Grades (%)
RLU	2
RCU	1
RCD	1
RAU	0
RAD	0
RFD	-
ULU	3
UCU	2
UCD	2
UAU	0

More precise definitions of the road types are presented in the guide. However, the road classification is defined as follows:

1st letter	R:	Rural
	U:	Urban
2nd letter	L:	Local
	C:	Collector
	A:	Arterial
	E:	Expressway
	F:	Freeway

The 3rd letter defines whether the road is divided

D: Divided
U: Undivided

An analysis of the specific problem resulting from the use of crossings with critical gradients by flatbed tractor-trailers with dropped chassis frames that can get stuck on the tracks or damage them is contained in Appendix B of this report. The problem is discussed using a geometric evaluation based on current standards and the planned RTD 10 standard for the profile of the most critical vehicle available on the market. The analysis makes it possible to determine that RTD 10 will greatly improve the situation faced by dropped chassis vehicles at crossings. In the worst case, there is a vertical clearance between the vehicle chassis and the rails, even if it is relatively small. In comparison, current standards allow a maximum vertical interference of about six inches between the chassis and the rails for the most critical cases. This is clearly inadequate and can cause incidents and damage to road vehicles and rails. Even if *Draft RTD 10* largely corrects this problem, the maintenance of the rails and the road, and good mechanical condition of the vehicles are nevertheless necessary to ensure that this type of vehicle can cross safely, even with the amendments made with the development of *Draft RTD 10*.

1.3.1.2 Driver perception-reaction time

The *Geometric Design Guide for Canadian Roads* also defines the perception-reaction times to use in the design, since these times are well documented and generally accepted. They are:

Table 7 (Table 1.2.2.1 of the *Geometric Design Guide*) – Perception and Reaction Time Design Domain

Perception and Reaction Time(s)	Applicability
0.5 – 2 s	Reaction of alerted drivers to simple stimulus.
2.5 s	Typically used as being representative of the 90th percentile of drivers and situations.
3.0 – 4.5 s	Reaction of unalerted drivers to complex or inconspicuous stimuli.

1.3.2 Heavy vehicle load and size limits

In Quebec, the *Vehicle Load and Size Limits Guide* from Transport Quebec defines the maximum loads and sizes of various types of heavy vehicles. In general, these Quebec standards correspond to what exists elsewhere in Canada. But in the United States, the standards differ from state to state with respect to traffic on secondary roads. These criteria, loads and sizes have a major influence on performance and, incidentally, on the calculations for the resulting sightlines and warning times.

The regulated loads and sizes, which are reduced during thaw, generally depend on the type of vehicle and number of axles. In Quebec, they are:

1 Straight truck, 2 axles

Maximum length: 12.5 m
Gross weight: 17,250 kg

2 Straight truck, 3 axles
    Maximum length: 12.5 m
    Gross weight: 25,250 kg

3 Straight truck, 4 axles
    Maximum length: 12.5 m
    Gross weight: 32,000 kg

4 Tractor with semi-trailer, 3 axles / Truck, 2 axles – with trailer, 1 axle
    Maximum length: 23 m
    Gross weight: 25,500 kg

5 Tractor with semi-trailer, 4 axles / Truck, 2 axles – with trailer, 2 axles
    Maximum length: 23 m
    Gross weight: 35,500 kg

6 Tractor with semi-trailer, 5 axles
    Maximum length: 23 m
    Gross weight: 41,500 kg

7 Truck, 2 axles – with trailer, 3 axles / Truck, 3 axles – with trailer, 2 axles
    Maximum length: 23 m
    Gross weight: 43,500 kg

8 Truck, 3 axles – with trailer, 3 axles / Truck, 4 axles – with trailer, 2 axles
    Maximum length: 23 m
    Gross weight: 51,500 kg

9 Truck, 3 axles – with trailer, 4 axles / Truck, 4 axles – with trailer, 3 axles
    Maximum length: 23 m
    Gross weight: 55,500 kg

10 A truck-train
    Maximum length: 25 m
    Gross weight: 53,500 kg

11 B and C truck-trains
    Maximum length: 25 m
    Gross weight: 59,000 kg

12 Bus
    Maximum length: 14 m
    Gross weight: ND

13 Articulated bus
    Maximum length: 18.5 m
    Gross weight: NA

Regarding forestry tractor semi-trailers used to carry tree-length wood on public roads, the maximum length of all the vehicles can be increased by 6 metres to account for wood that is cantilevered behind the semi-trailer.

1.3.3 RTD 10 – Road/Railway Grade Crossings: Technical Standards and Inspections, Testing and Maintenance Requirements

The draft RTD 10, initiated to compensate for a lack of precise standards for designing and inspecting grade crossings, has been under development for several years. Although it is not yet officially in effect, it is still used in Canada for designing new grade crossings.

RTD 10 is subdivided into four parts:

- Introduction
- Design standards
- Grade Crossing Warning System Technical Requirements
- Maintenance, Inspection and Testing

Only some parts of the design standards section are of interest here and will be looked at in more detail. They are mainly the sections about determining sightlines and the sections that have an impact on sightlines. They are presented in the same order as in the draft, although rearranging the order of the sections would probably help better understand the standard.

1.3.3.1 Choosing a design vehicle

Since the design of a grade crossing must take vehicle length and vehicle braking and acceleration criteria into account, RTD 10 first proposes choosing a design vehicle from the classes of vehicles defined in the *Geometric Design Guide for Canadian Roads*. These classes are shown in Table 8. Since these were developed to determine road characteristics of which some, such as turning radius, have no impact on grade crossing design, there is some question as to whether they are appropriate for designing grade crossings.

Table 8 – Vehicle Classes (Draft RTD 10)
(Table 4-1: General Vehicles)

Class	General Vehicle Descriptions	Length (m)
Passenger Car	1. Passenger Cars, Vans, and Pickups (P)	5.6
Trucks		
Single-Unit Trucks	2. Light Single-Unit Trucks	6.4
	3. Medium Single-Unit Trucks	10.0
	4. Heavy Single-Unit Trucks	11.5
Tractor Trailers	5. WB-19 Tractor-Semi trailers	20.7
	6. WB-20 Tractor-Semi trailers	22.7
Combination Vehicles	7. A-Train Doubles (ATD)	24.5
	8. B-Train Doubles (BTD)	25.0
Buses	9. Standard Single-Unit Buses (B-12)	12.2
	10. Articulated Buses (A-BUS)	18.3
	11. Intercity Buses (I-BUS)	14.0

Once the vehicle classes have been defined, the design vehicle is chosen according to the type of region and road in the immediate area of the grade crossing to be designed, as shown in Table 9.

Although this selection makes it possible to determine certain criteria required for the grade crossing design, it seems rather rigid because the type of vehicle that can travel on a road depends on multiple factors that cannot initially be reduced to one type of road and one region.

Table 9 – Design Vehicle Selection (Draft RTD 10)

(Table 4-3: Design Vehicle Selection)

Road Use	Descriptions	Design Vehicles
Local roads serving seasonal residences	Summer and winter areas	Single-unit trucks
Tourist area	Self propelled or towed recreational vehicles	Single-unit trucks, special vehicle – recreation
Agricultural area	Private road grade crossing serving agricultural use or local public roads within the area	Single-unit trucks, buses, truck tractors with semi trailers, combination vehicles with B train doubles or special vehicles such as farm tractors with trailers, towed cultivating or harvesting equipment, or large self propelled cultivating and harvesting machinery
Access roads to residential property	Where the traffic stream is almost exclusively residential use	Passenger car, light van, and pickup
	Where the users have large trucks or special vehicles	Single-unit trucks, truck tractors with semi trailers, or special vehicle – recreational
Industrial	Private roads	Single-unit trucks, truck trailers with semi-trailers, A or B train doubles, or special vehicle – machinery or long combination vehicle
	Public grade crossings within an industrial area	Combination vehicles
	Resource road	Single-unit trucks, tractor trailers, combination vehicles, special vehicle – off road mining, long load logging trucks
Local residential road	Regular use by commercial delivery vehicles, moving vans, road maintenance vehicles and garbage trucks	Single-unit trucks, buses
Residential collector	Regular use by commercial delivery vehicles, moving vans, road maintenance vehicles, garbage trucks, or buses	Single-unit trucks, buses
Urban and rural arterial roads		Combination vehicles, buses
Designated truck route		Combination vehicles
Designated special vehicle route		Special vehicle – long load logging truck or long combination vehicle

1.3.3.2 Stopping sight distance

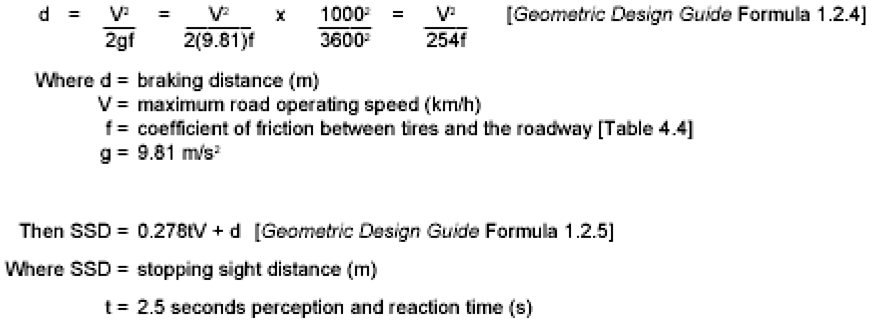
RTD 10 defines the stopping sight distance as the distance required for drivers to bring a vehicle to a stop before a crossing if they see a train coming, in the case of a passive crossing, or if the light signals are activated, in the case of an active crossing.

This distance is the sum of the distance travelled during the driver's perception and reaction time and the braking distance of the vehicle if the driver is travelling at the posted speed limit. The draft suggests the following formula for calculating the braking distance and the stopping sight distance.

Note that the values in Table 4.4 were obtained in tests conducted in 1950 using automobiles with locked wheels on wet asphalt, and all evidence suggests that these braking distances are not typical of the capabilities of modern vehicles.

The equation above is derived directly from the dynamic ratios for a movement involving constant acceleration and the *Geometric Design Guide*, but it should be noted that it does not take the vehicle type into account, although it proposes a modification for trucks without mentioning exactly which modification to use. Nevertheless, Table 11 lists the values to use to determine the stopping sight distance for a car or truck according to the maximum road operating speed.

Table 10 – Formula for Calculating the Stopping Sight Distance (RTD 10)



$$d = \frac{V^2}{2gf} = \frac{V^2}{2(9.81)f} \times \frac{1000^2}{3600^2} = \frac{V^2}{254f}$$ [*Geometric Design Guide* Formula 1.2.4]

Where d = braking distance (m)
V = maximum road operating speed (km/h)
f = coefficient of friction between tires and the roadway [Table 4.4]
$g = 9.81\ \text{m/s}^2$

Then $SSD = 0.278tV + d$ [*Geometric Design Guide* Formula 1.2.5]

Where SSD = stopping sight distance (m)

t = 2.5 seconds perception and reaction time (s)

Table 4-4: Coefficient of Friction for Wet Pavements and Gravel

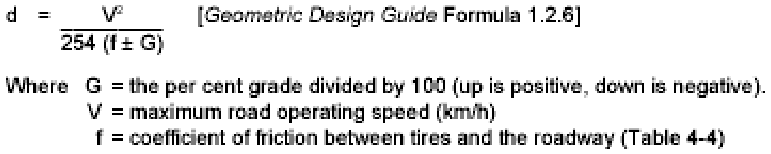
Maximum Road Operating Speed (km/h)	Coefficient of Friction (f)
30	0.40
40	0.38
40 – 50	0.35
55 – 60	0.33
63 – 70	0.31
70 – 80	0.30
77 – 90	0.30
85 – 100	0.29
91 – 110	0.28
98 – 120	0.28

Table 11 – Stopping Sight Distances (RTD 10)

Table 4-5: Stopping Sight Distances *(level grade, on wet pavement and gravel surfaces)*

Maximum Road Operating Speed (km/h)	Passenger Car Class (m)	Truck Class (m)
40	45	70
50	65	110
60	85	130
70	110	180
80	140	210
90	170	265
100	210	330
110	250	360

To take into account the grade of the road, the following equation should be used (Ref.: RTD 10):



$$d = \frac{V^2}{254\,(f \pm G)}$$ [*Geometric Design Guide* Formula 1.2.6]

Where G = the per cent grade divided by 100 (up is positive, down is negative).
V = maximum road operating speed (km/h)
f = coefficient of friction between tires and the roadway (Table 4-4)

1.3.3.3 Grade crossing clearance distance

RTD 10 defines the grade crossing clearance distance as the unsafe zone that a vehicle must travel across to completely clear a crossing. The minimum length of this zone is defined by the distance between a line located 5 m in advance of the closest rail and a line located 2.4 m beyond the farthest rail. This distance is determined as follows:

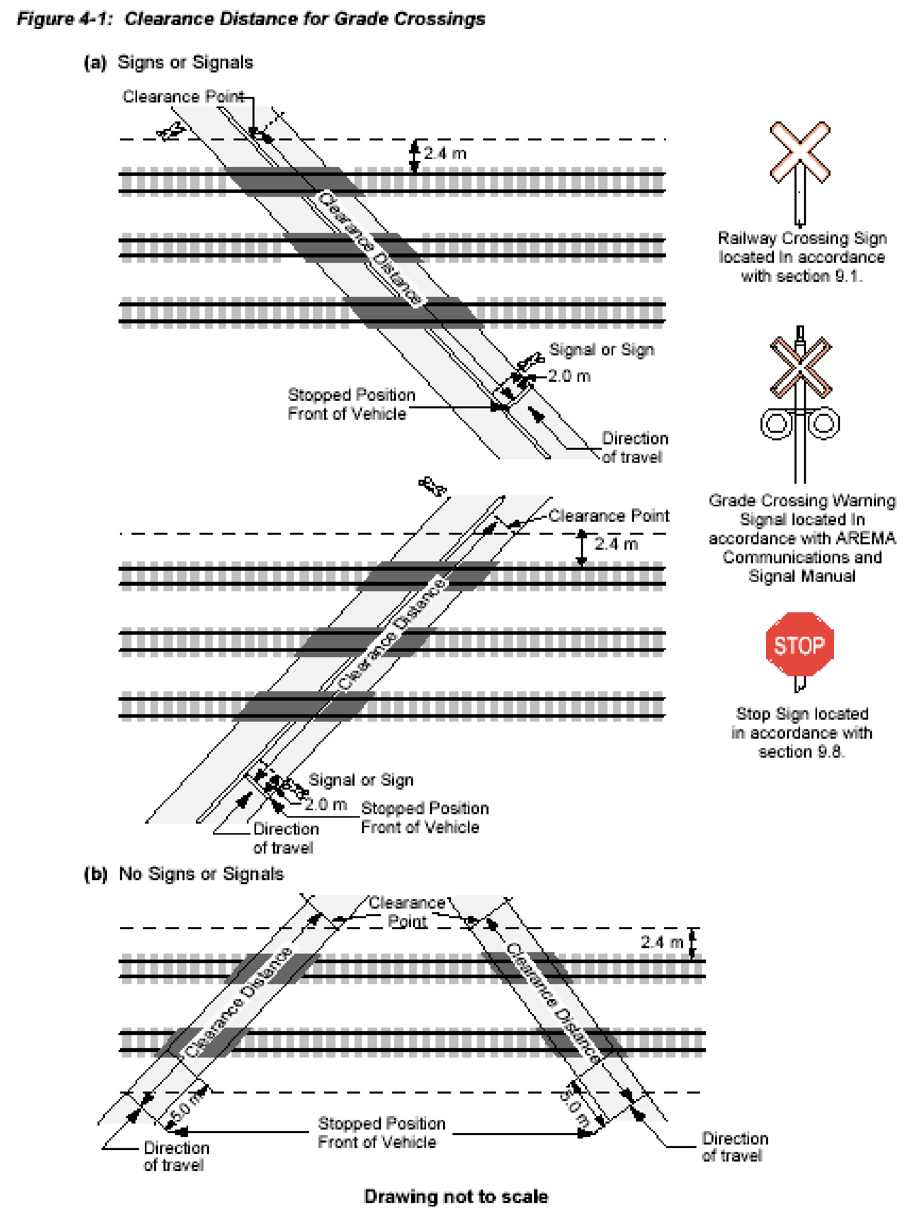


Figure 1 – Clearance Distance Measurements (RTD 10)

The design vehicle must thus travel the sum of this distance and the length of the vehicle to completely clear the crossing safely.

1.3.3.4 Design vehicle departure time

RTD 10 the defines the design vehicle departure time as the time required for the vehicle to pass completely through the crossing clearance distance from a complete stop. To be safe, the departure time must include the driver's perception and reaction time.

RTD 10 does not give a precise method for determining this departure time, but gives the following acceleration curves as a guide:

Figure 4-2 Assumed Acceleration Curves - General Design Vehicles
(Geometric Design Guide)

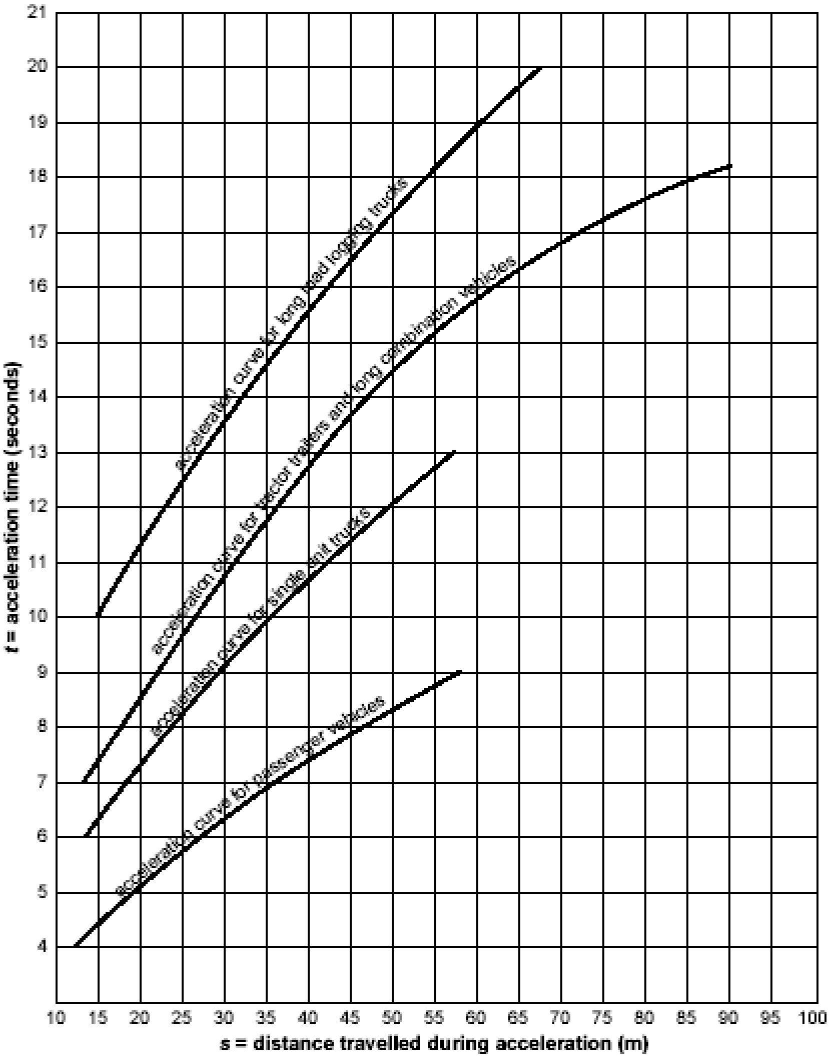


Figure 2 – Design Vehicle Acceleration Curves (RTD 10)

These curves are given as a guide only because they were obtained under ideal conditions and do not reflect reality. However, no method is suggested for determining the acceleration of design vehicles in real conditions. Note that these curves are taken from the *Geometric Design Guides*, but do not reflect the different vehicle classes defined in Table 8.

RTD 10 also mentions certain factors that should be taken into account in the departure time calculations. The following factors could influence and slow vehicle acceleration:

- condition of the road surface
- condition of the grade crossing surface
- superelevated track
- an intersection on the far side of the grade crossing where vehicles are required to stop, which will slow vehicle acceleration over the crossing

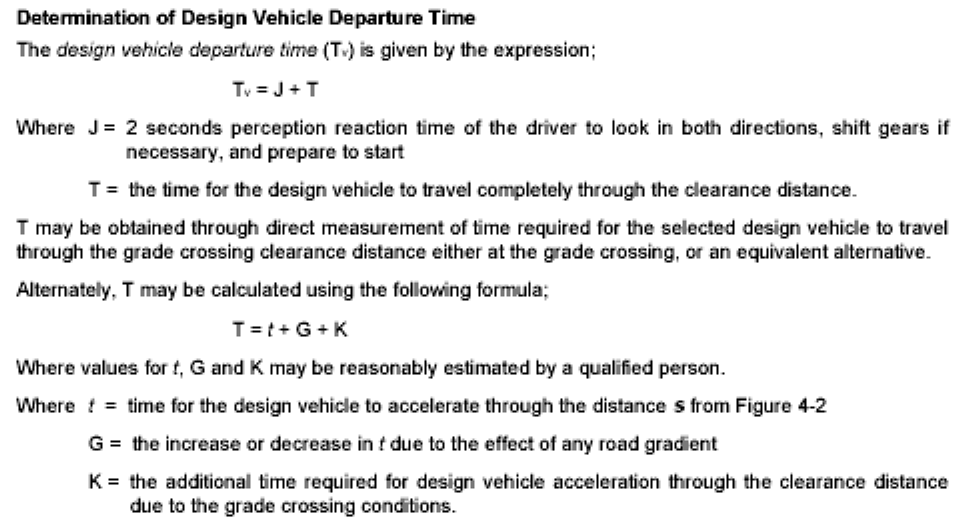
- restrictions on the vehicle operator from shifting gears while passing over the grade crossing
- non-standard placement of stop line pavement markings.

Another factor that influences departure time is the road gradient. RTD 10 proposes the following method to take gradient into account in calculating the departure time:

Table 12 – Ratios of Acceleration Times on Grades (RTD 10)

Table 4-6: Ratios of Acceleration Times on Grades

Design Vehicle	**Road Grade (%)**				
	-4	-2	0	+2	+4
Passenger Car	0.7	0.9	1.0	1.1	1.3
Single Unit Truck and Buses	0.8	0.9	1.0	1.1	1.3
Tractor – Semi trailer	0.8	0.9	1.0	1.2	1.7



Determination of Design Vehicle Departure Time

The *design vehicle departure time* (T_v) is given by the expression;

$$T_v = J + T$$

Where J = 2 seconds perception reaction time of the driver to look in both directions, shift gears if necessary, and prepare to start

T = the time for the design vehicle to travel completely through the clearance distance.

T may be obtained through direct measurement of time required for the selected design vehicle to travel through the grade crossing clearance distance either at the grade crossing, or an equivalent alternative.

Alternately, T may be calculated using the following formula;

$$T = t + G + K$$

Where values for t, G and K may be reasonably estimated by a qualified person.

Where t = time for the design vehicle to accelerate through the distance **s** from Figure 4-2

G = the increase or decrease in t due to the effect of any road gradient

K = the additional time required for design vehicle acceleration through the clearance distance due to the grade crossing conditions.

Although it is not mentioned, Table 12 is taken from the *Geometric Design Guide* (Table 2.3.3.2 of the TAC guide). However, the formula used here to account for the road grade is not clear because value G in Table 4-6 is added to the departure time on level terrain, while the *Geometric Design Guide* clearly states that G is a multiplication factor of the departure time on level terrain (p. 2.3.3.6 of the TAC guide). The latter method of handling a grade is much more logical because the difference between the departure time on level terrain and on a grade necessarily depends on the length of the distance to cover and thus cannot be a constant value.

Since no concrete method is proposed to determine the real departure time, an appropriate method will eventually have to be developed.

1.3.3.5 Location of grade crossings, grade crossing surface and road geometry

In RTD 10 these sections are separate, but they have been grouped together here because they define certain factors that can influence departure times.

First, the minimum distance between a road intersection and a grade crossing is set at 30 metres. This distance is determined as described in Figure 3. However, this distance of 30 metres is not always respected at existing crossings. Nevertheless, proper synchronization between traffic lights at the intersection and the crossing warning system can make it possible to safely use a distance of less than 30 metres.

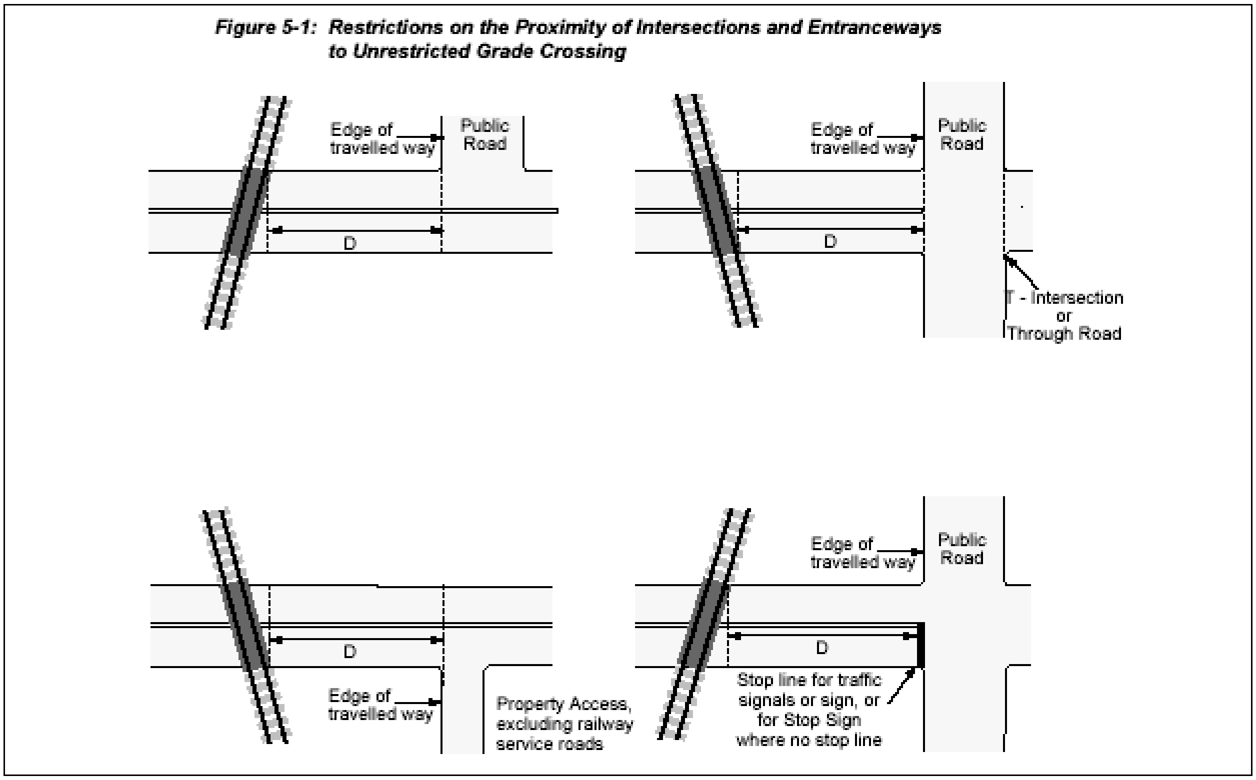


Figure 5-1: Restrictions on the Proximity of Intersections and Entranceways to Unrestricted Grade Crossing

Figure 3 – Minimum Distance Between a Grade Crossing and an Intersection (RTD 10)

Another standard defines the characteristics of the crossing surface, but not all aspects will be described here. The elements that most affect the crossing time are the flangeway width and the difference between the height of the rails and the road surface. RTD 10 defines the worst surfaces by the maximum flangeway width and the difference in height:

- the maximum flangeway width may be not less than 2.5 inches (63.5 mm) and not more that 4.75 inches (120.6 mm); and
- the height of rail may extend up to 1 inch (25.4 mm) above or below the top of the crossing surface.

The maximum values for these standards will be used in determining the worst crossing times for design vehicles.

One of the standards that probably has the greatest influence on crossing times is the one defining road geometry. In this sense, all the aspects of this standard are important. They are (Ref.: RTD 10):

7.1 (a) The horizontal and vertical alignment of the road approach and the road over the grade crossing shall be smooth and continuous within the safe stopping sight distance.

(b) The horizontal alignment of the road over the tracks shall be straight extending beyond the outside rails for a distance equal to the length of the design vehicle.

(c) The profile and elevation of the grade crossing surface and the rest of the road shall match and safely accommodate the maximum road operating speed in accordance with the design standards of the *Geometric Design Guide*.

7.2 Subject to the conditions in subsection 7.1 and except to provide for vehicular grade crossings of super-elevated track as required in subsection 7.4, the maximum gradients for roads at a grade crossing shall not exceed the following:

(a) ratio of 1:50 (2 per cent) within 8 m of the nearest rail and 1:20 (5 per cent) for 10 m beyond, at unrestricted grade crossings for vehicular use;

(b) ratio of 1:50 (2 per cent) within 8 m of the nearest rail and 1:10 (10 per cent) for 10 m beyond, at any other grade crossing for vehicular use;

(c) ratio of 1:50 (2 per cent) within 5 m of the nearest rail at grade crossings for pedestrian or cyclist use only; and

(d) ratio of 1:100 (1 per cent) within 5 m of the nearest rail at grade crossings specifically identified as a route for persons using assistive devices.

7.3 Roads in grade crossings constructed before(CIF), shall conform to the following:

a) in the case of a public grade crossing for vehicular use, the ascending or descending gradients of roads shall not exceed a vertical to horizontal ratio of 1:20 (5 per cent), unless authorized by the National Transportation Agency prior to January 1, 1989 under the *Railway Act*, or the Minister of Transport for Canada after that date, under the *Railway Safety Act*; and

b) in the case of other grade crossings, the ascending or descending gradients shall be safe for the use to which the grade crossing is put.

7.4 At vehicular grade crossings incorporating superelevated track, the difference between the gradient of the grade crossing surface on superelevated track and the gradient of the adjacent road shall not exceed the limits specified in the *Geometric Design Guide*.

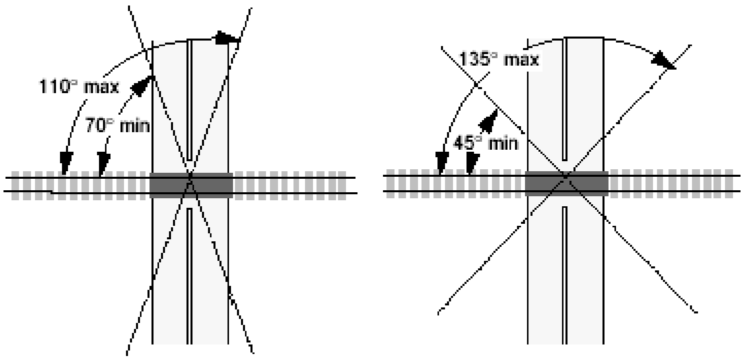
7.5 The width of the travelled road lanes and shoulders at the grade crossing surface shall not be less than on the road approaches.

7.6 A grade crossing where the maximum railway operating speed exceeds 15 mph shall be constructed as specified in Figure 7-1, with the angle of intersection between the road and the track of:

(a) not less than 70 nor greater than 110 degrees without a grade crossing warning system; or

(b) not less than 45 nor greater than 135 degrees with a grade crossing warning system.

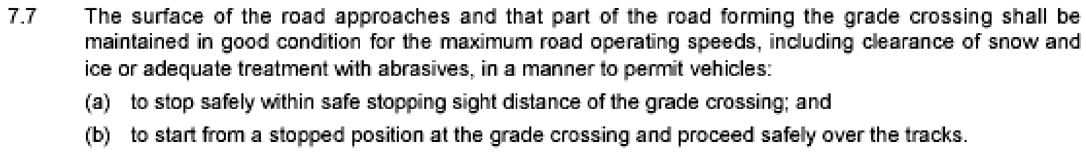
Figure 7-1: Maximum Crossing Angle: Grade Crossings



a) Crossings without Grade Crossing Warning System.

b) Crossing with Grade Crossing Warning System.

Drawing not to scale



7.7 The surface of the road approaches and that part of the road forming the grade crossing shall be maintained in good condition for the maximum road operating speeds, including clearance of snow and ice or adequate treatment with abrasives, in a manner to permit vehicles:

(a) to stop safely within safe stopping sight distance of the grade crossing; and

(b) to start from a stopped position at the grade crossing and proceed safely over the tracks.

The geometry of the road and the crossing to be designed or inspected, within the limitations of these standards, should be used to determine the crossing time for design vehicles at this crossing.

1.3.3.6 Sightlines

RTD 10 defines the sightlines as the distance of clear view required to be able to see the approach of a train. At passive grade crossings, it is obvious that these sightlines must be clear, but at grade crossings with a warning system, it is still suggested that these sightlines be cleared. There are three different types of sightlines:

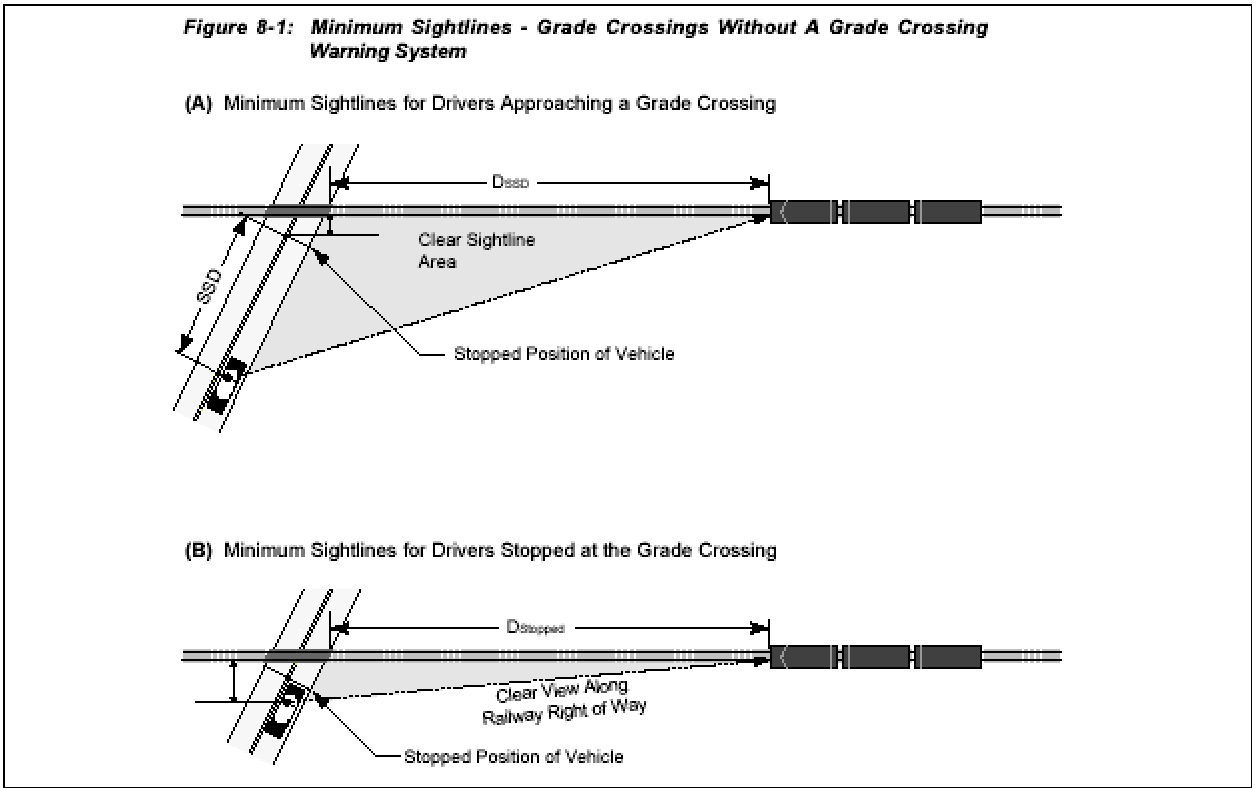


Figure 8-1: Minimum Sightlines - Grade Crossings Without A Grade Crossing Warning System

(A) Minimum Sightlines for Drivers Approaching a Grade Crossing

(B) Minimum Sightlines for Drivers Stopped at the Grade Crossing

Figure 4 – Sightlines for Passive Grade Crossings (RTD 10)

Figure 8-2: Minimum Sightlines - Grade Crossings with a Grade Crossing Warning System

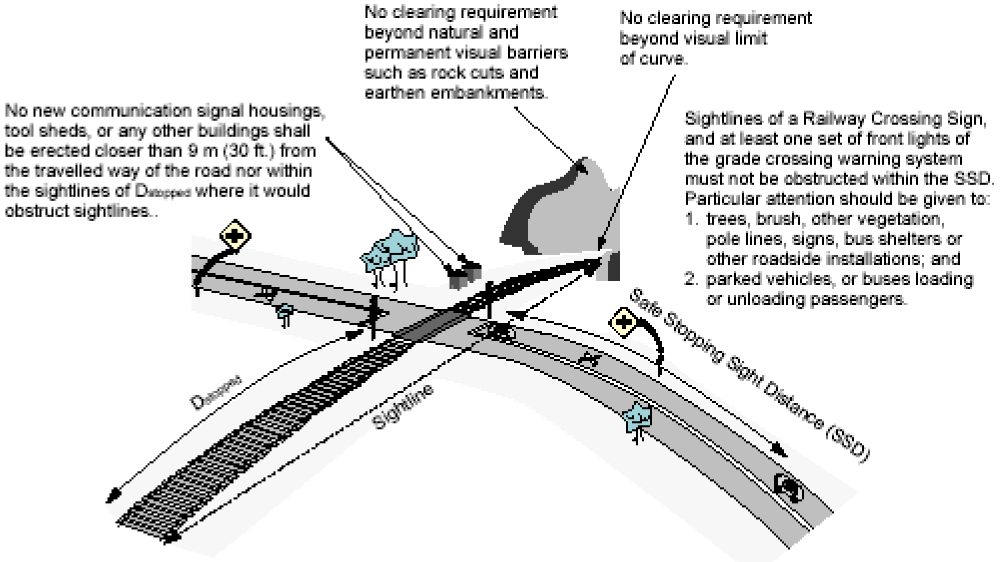
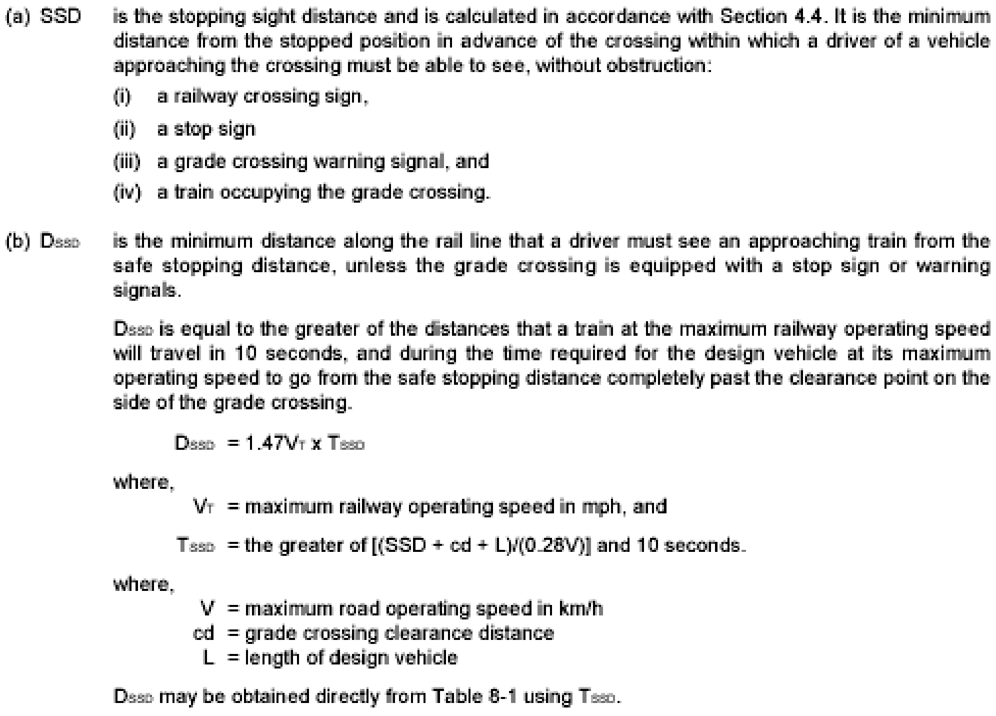


Figure 5 – Sightlines for Active Grade Crossings (RTD 10)

The first two sightlines are calculated to form a sight triangle that must be clear at all times:



(a) SSD is the stopping sight distance and is calculated in accordance with Section 4.4. It is the minimum distance from the stopped position in advance of the crossing within which a driver of a vehicle approaching the crossing must be able to see, without obstruction:

(i) a railway crossing sign,
(ii) a stop sign
(iii) a grade crossing warning signal, and
(iv) a train occupying the grade crossing.

(b) D_{SSD} is the minimum distance along the rail line that a driver must see an approaching train from the safe stopping distance, unless the grade crossing is equipped with a stop sign or warning signals.

D_{SSD} is equal to the greater of the distances that a train at the maximum railway operating speed will travel in 10 seconds, and during the time required for the design vehicle at its maximum operating speed to go from the safe stopping distance completely past the clearance point on the side of the grade crossing.

$$D_{SSD} = 1.47V_T \times T_{SSD}$$

where,

V_T = maximum railway operating speed in mph, and
T_{SSD} = the greater of [(SSD + cd + L)/(0.28V)] and 10 seconds.

where,

V = maximum road operating speed in km/h
cd = grade crossing clearance distance
L = length of design vehicle

D_{SSD} may be obtained directly from Table 8-1 using T_{SSD}.

(c) $D_{Stopped}$ is the distance along the rail line from the grade crossing that a train operating at the maximum railway operating speed will travel during the Departure Time for the grade crossing design vehicle calculated in accordance with Section 4.7, or the Departure Time for pedestrians, cyclists, and persons using assistive devices calculated in accordance with Section 4.8.

$D_{Stopped}$ may be calculated by the following formula:

$$D_{Stopped} = 1.47V \times T_d \quad \text{(ft.)}$$

where,

V = the maximum railway operating speed along the rail line (mph)
T_d = the Departure Time, calculated in accordance with Section 4.7 or 4.8.

$D_{Stopped}$ may be obtained directly from Table 8-1 using T_d.

Table 13 shows the prescribed values for these sightlines along railway lines.

The general calculation method for the sightlines seems adequate, but there are still some inconsistencies and contradictions in the calculations. First, mixed use of the international and imperial systems can lead to confusion. Moreover, the units used for some variables are not mentioned. It would thus be preferable to choose one of the two measurement systems, or better yet, identify all the parameters. In addition, as we already pointed out earlier, the method to calculate the SSD uses values that are not realistic because they are very outdated.

Furthermore, in the D_{SSD} calculation, first the T_{SSD} must be determined, and then 10 seconds must be used if the calculated value is less than 10 seconds. However, a preliminary evaluation indicates that this minimum time of 10 seconds is too low and that at any rate, the T_{SSD} calculation is skewed by the use of the SSD parameter, whose value is not realistic.

Table 13 – Sightlines Along Rail Lines (RTD 10)

Table 8-1: Required Sightlines Along the Rail Line (D_{SSD} and $D_{Stopped}$)
Fig. 8-1 and Fig. 8-2

Maximum Railway Operating Speed (V_T)	Required Sightlines Along Rail Line (D_{SSD} and $D_{stopped}$) Departure time T_d and T_p (en seconds)											Above 20 seconds add for each additional second
	minimum 10	11	12	13	14	15	16	17	18	19	20	
Mph	**metres**											
STOP	30	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
1-10	45	50	55	60	65	70	71.52	75.99	80.46	85	90	+5
11-20	90	100	110	120	125	135	145	155	165	170	180	+10
21-30	135	150	165	175	190	205	215	230	245	255	270	+15
31-40	180	200	220	235	250	270	285	305	325	340	360	+20
41-50	225	250	270	290	315	335	360	380	405	425	450	+25
51-60	270	300	325	350	380	405	430	460	485	510	540	+30
61-70	315	350	380	415	445	470	505	535	565	595	630	+35
71-80	360	395	435	465	505	540	580	610	650	680	720	+40
81-90	405	445	490	535	570	605	650	685	730	765	810	+45
91-100	450	500	540	580	630	670	715	760	805	850	895	+50

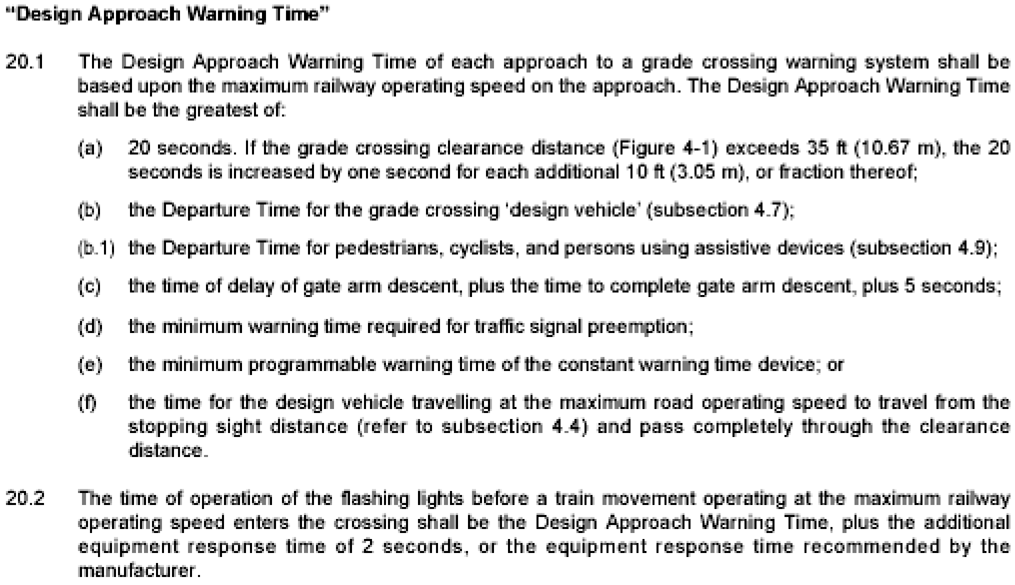
Note: To use Table 8-1, it is necessary to first calculate the departure time required for the crossing in accordance with this section and to determine the maximum railway operating speed. Then selecting the horizontal line in the Table corresponding to the maximum railway operating speed, move to the right to the column under the departure time required for the crossing, in which the sightline distance along the railway is found.

In addition, since the sightline design is based on the maximum train speed, it seems illogical to consider a stopped train, as is shown in the first line of Table 8.1.

Finally, to calculate $D_{Stopped}$, the design vehicle departure time must be known and the method refers to this calculation. However, as mentioned earlier, no concrete method is proposed to evaluate the real departure time.

1.3.3.7 Warning time

Determining the warning time is not discussed in the design standards, but in another section of RTD 10, which seems odd. This time is defined as the time between the moment that the warning systems are activated (bells and flashing lights) and the arrival of the train. Since determining these times is based on the same calculations as the sightlines, the same comments for sightlines apply. According to RTD 10, this time should be determined as follows:



"Design Approach Warning Time"

20.1 The Design Approach Warning Time of each approach to a grade crossing warning system shall be based upon the maximum railway operating speed on the approach. The Design Approach Warning Time shall be the greatest of:

(a) 20 seconds. If the grade crossing clearance distance (Figure 4-1) exceeds 35 ft (10.67 m), the 20 seconds is increased by one second for each additional 10 ft (3.05 m), or fraction thereof;

(b) the Departure Time for the grade crossing 'design vehicle' (subsection 4.7);

(b.1) the Departure Time for pedestrians, cyclists, and persons using assistive devices (subsection 4.9);

(c) the time of delay of gate arm descent, plus the time to complete gate arm descent, plus 5 seconds;

(d) the minimum warning time required for traffic signal preemption;

(e) the minimum programmable warning time of the constant warning time device; or

(f) the time for the design vehicle travelling at the maximum road operating speed to travel from the stopping sight distance (refer to subsection 4.4) and pass completely through the clearance distance.

20.2 The time of operation of the flashing lights before a train movement operating at the maximum railway operating speed enters the crossing shall be the Design Approach Warning Time, plus the additional equipment response time of 2 seconds, or the equipment response time recommended by the manufacturer.

Here, T_D and T_{SSD} correspond to the times determined in b) and f), respectively. The minimum of 20 seconds presented in a) seems safe, but this should be determined in later tests.

1.3.4 Provincial regulations governing mandatory stops and that prohibit changing of gears on crossings

Various provisions in the highway codes of different provinces require certain vehicles (mainly heavy vehicles) to stop at grade crossings or to cross without shifting gears. The legislation varies considerably from one Canadian province to the next. These regulations have a significant impact on the departure times of the vehicles they govern, and it is important that they are well known so that the departure times for these vehicles are calculated correctly. The complete sections of the provincial acts are contained in Appendix C of this report. However, a summary highlighting certain important points follows.

British Columbia

- The following vehicles must stop at all passive crossings:
  - buses carrying paying passengers;
  - school buses;
  - vehicles carrying explosive substances;
  - vehicles carrying poisonous substances;
  - vehicles carrying flammable substances;
  - vehicles (empty or full) used to carry flammable liquids or gas.

- No vehicles that have stopped at any sort of grade crossing (vehicles mentioned above, all vehicles stopped at a mandatory stop, all vehicles stopped at a warning device) may shift gears when crossing railway lines.

Alberta

- The following vehicles must stop at all passive crossings:
  - school buses;
  - vehicles carrying explosive substances;
  - vehicles carrying inflammable substances;
  - vehicles (empty or full) used to carry inflammable liquids or gas.

- No vehicles that have stopped at any sort of grade crossing (vehicles mentioned above, all vehicles stopped at a mandatory stop, all vehicles stopped at a warning device) may shift gears when crossing railway lines.

Saskatchewan

- The following vehicles must stop at all passive crossings:
  - school buses;
  - vehicles requiring a placard pursuant to the *Dangerous Goods Transportation Act*, i.e., any vehicle carrying dangerous goods.

- Only school buses with manual transmissions must cross railway lines in first gear.

Manitoba

- The following vehicles must stop at all passive crossings:
  - buses carrying paying passengers;
  - school buses;
  - vehicles (empty or full) used to carry inflammable liquids or gas.

- The vehicles listed above may not shift gears when crossing railway lines at passive crossings.

Ontario

- The following vehicles must stop at all passive crossings:
  - public vehicles;
  - school buses.

- The vehicles listed above may not shift gears when crossing railway lines at passive crossings.

Nova Scotia

There is no legislation requiring a mandatory stop or prohibiting the shifting of gears when crossing railway lines in this province.

Prince Edward Island

There are no longer any trains in this province.

Quebec

- The following vehicles must stop at all crossings (active and passive) *:
  - buses;
  - minibuses;
  - vehicles carrying dangerous substances of a sufficient quantity to require a placard indicating danger pursuant to the *Transportation of Dangerous Substances Regulation*.

  * The *Highway Safety Code* presently sets out that all heavy vehicles must stop at all crossings, but Bill 58 (9 December 1999) abolishes this obligation (only what is written above remains effective). However, this bill has not yet been officially passed.

- No legislation prohibits the shifting of gears when crossing railway lines in Quebec.

New Brunswick

- The following vehicles must stop at all crossings (active and passive):
  - vehicles carrying passengers for compensation;
  - any type of bus;
  - vehicles carrying explosive substances;
  - vehicles carrying flammable liquids.

- The vehicles listed above may not shift gears when crossing railway lines.

Newfoundland and Labrador

- The following vehicles must stop at all crossings (active and passive):
  - vehicles carrying passengers for compensation;
  - school buses;
  - vehicles carrying explosive substances;
  - vehicles carrying inflammable liquids.

- The vehicles listed above may not shift gears when crossing railway lines.

Yukon Territory

In theory, this territory has the same legislation governing mandatory stops and the shifting of gears when crossing railway lines as Alberta, but in practice, the regulations are not applied. This is due to the very small number of trains that travel in this territory and to the fact that it is now mandatory for signals to be installed at all crossings to warn of trains. No accidents have occurred at grade crossings in this territory in recent years.

Northwest Territories and Nunavut

Since these two territories were recently divided, they have the same regulations:

- Only school buses must stop at all crossings in these territories.

School buses cannot shift gears when crossing railway lines.

1.4 Studies on the acceleration and braking of heavy vehicles

In the past, many studies have been carried out to determine the acceleration and braking performances of heavy vehicles. The results of some of these studies are presented below in relation to RTD 10.

1.4.1 Acceleration

To calculate the sightlines along railway tracks, RTD 10 proposes using the acceleration curves produced for four design vehicles, but unfortunately it does not explain clearly how to use them. Nevertheless, the draft proposes using a minimum sightline along the railway that is based on a departure time of 10 seconds at passive crossings, and a minimum warning time of 20 seconds at active crossings. Many studies have determined that these minimum departure times were insufficient in many cases. Their results are presented below.

One of the main studies in this area was done by Kenneth Kendall and Lise Morrissette in 1995. The direct objective of their study was to determine whether using the 10-second rule as the minimum departure time for passive crossings allowed heavy vehicles to clear a crossing safely. The study was conducted at a weigh station in Ontario where the test vehicles were chosen at random. In all, 215 heavy vehicles of different types were selected, consisting of 4 straight trucks, 163 tractor-trailers and 47 truck-trains, most of which were filled to full capacity. Tests were conducted to determine the departure time for these vehicles along distances equivalent to crossings with one, two, three or four tracks. Three types of tests were done for each vehicle: a test at maximum acceleration using all the transmission ratios, a test using all the possible transmission ratios up to the equivalent of the first track, and a test according to the policies of the transportation company. The results of the study are shown in Table 14.

The results are grouped and no distinction has been made between the different types of tests. Nevertheless, Kendall and Morrissette compared the departure time of various vehicles and their weights for each distance (1, 2, 3 and 4 tracks). Figure 6 illustrates this comparison for all the vehicles for a 1-track crossing. Aside from the general trend that shows a general increase in departure time according to weight, it is difficult to see a clear relation in this graph. At the end of the study, Kendall and Morrissette drew the following conclusions:

- No type of fully-loaded heavy vehicle can safely clear a 4-track crossing within the minimum 10-second sightline prescribed by legislation.
- An empty tractor-trailer cannot safely clear a 4-track crossing within the minimum 10-second sightline prescribed.
- A fully loaded tractor-trailer cannot safely clear a 1-track crossing within the minimum 10-second sightline prescribed.
- An empty truck-train cannot safely clear a 1-track crossing within the minimum 10-second sightline prescribed.
- A fully loaded truck-train cannot safely clear a 1-track crossing within the minimum 10-second sightline prescribed.

- A transportation vehicle cannot safely clear a 1-track crossing within the minimum 10-second sightline prescribed.

Table 14 – Results of the Kendall & Morrissette Study, 1995

	STRAIGHT	T-TRAILER	T-TRAIN	ALL
RAW DATA				
Total Vehicles	4	163	47	215
Full Vehicles	3	159	40	203
Empty Vehicles	1	4	7	12
1 – Track Slow	7.0	29.97	26.74	29.97
1 – Track Fast	4.49	6.00	606	4.49
2 – Track Slow	8.17	36.06	29.27	36.06
2 – Track Fast	5.79	6.78	6.92	5.79
3 – Track Slow	9.37	40.36	33.42	40.36
3 – Track Fast	6.59	7.47	7.55	6.59
4 – Track Slow	11.05	44.80	37.91	44.80
4 – Track Fast	7.18	7.82	8.18	7.18
Lightest (KG)	6410	11390	20250	6410
Heaviest (KG)	14120	62520	63500	63500
Longest (M)	9.40	22.84	24.80	24.80
Shortest (M)	8,00	11.40	18.74	8.00
MEDIAN				
Weight (KG)	9285	44820	57830	46540
Length (M)	9.48	19.23	22.40	19.72
1 – Track Time	6.08	11.74	13.35	11.80
2 – Track Time	7.35	13.06	14.24	13.12
3 – Track Time	8.60	13.99	15.51	14.23
4 – Track Time	9.61	14.88	16.45	15.33
AVERAGE				
Weight (KG)	9775	41704	51385	43271
Length (M)	9.19	19.04	22.56	19.54
1 – Track Time	5.92	12.40	14.40	12.73
2 – Track Time	7.17	13.74	15.75	14.07
3 – Track Time	8.29	14.92	16.94	15.25
4 – Track Time	9.36	15.89	18.01	16.24

Based on these conclusions, Kendall and Morrissette determined that it would not be safe to use sightlines based on a minimum of 10 seconds, and that doing so would only increase the potential of collision between a train and a heavy vehicle at a crossing.

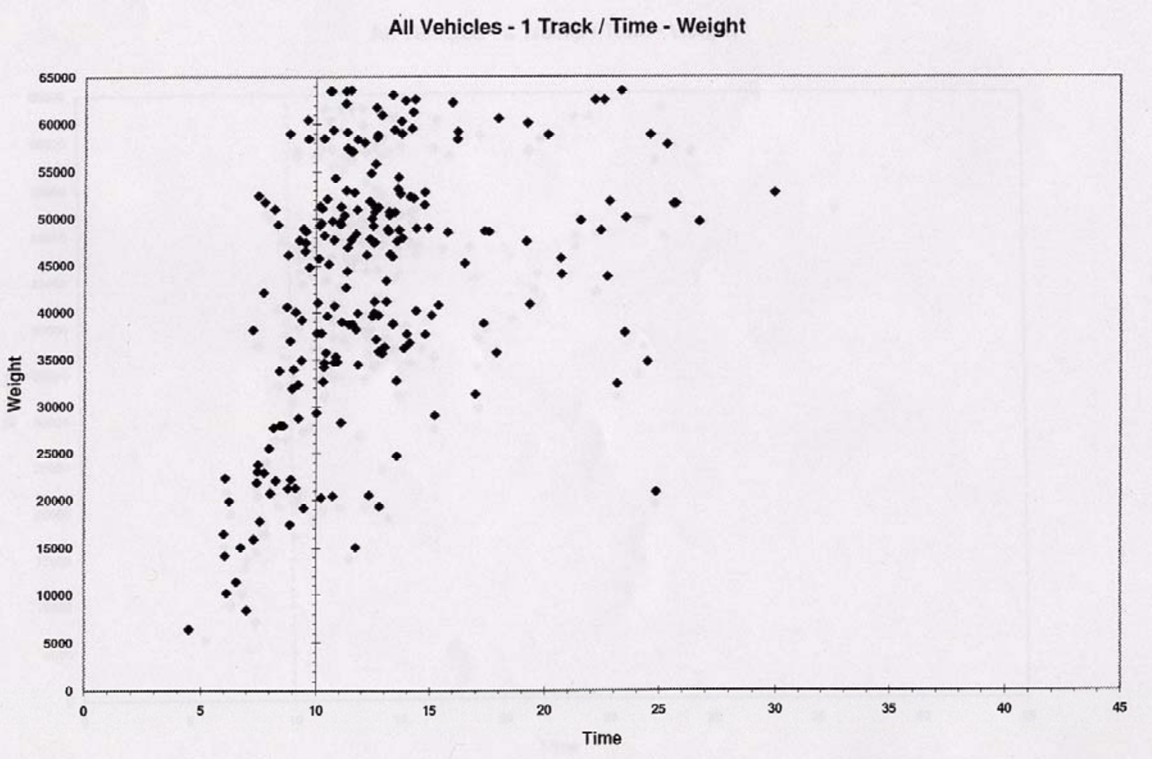


Figure 6 – Departure Time by Weight for One Track (Kendall & Morrissette, 1995)

The Kendall and Morrissette study demonstrates that sightlines based on a minimum departure time of 10 seconds are clearly insufficient. However, this study does not offer a realistic characterization of the real performances of heavy vehicles. First, it was conducted in ideal conditions: a road perpendicular to the tracks, a completely level crossing, a uniform crossing surface in good condition and drivers who were accelerating at maximum speed. Second, the authors themselves state that they did not situate their results in relation to several criteria that have a significant effect on the performances of the heavy vehicles.

The authors first observed that the type of engine and transmission and their various combinations could greatly affect the performance of such vehicles. They noted that Caterpillar engines seemed to be the slowest (engine speed) and that Cummins engines were the fastest. They also noted that the greater the number of transmission ratios, the greater the number of gear changes required to reach a given speed and consequently the longer the acceleration time.

They observed that some vehicles had a deep reduction gear allowing them to start with very heavy loads or on steep slopes. In their tests, use of this transmission ratio was observed on two occasions. Use of this ratio, combined with a company policy of not shifting gears and using a maximum engine speed of 1600 rpm, resulted in the slowest acceleration times of all (66% to 78% slower than the average for similar vehicles).

The authors also observed that the vehicles had dragging brakes in some cases, which could affect the acceleration criteria of these vehicles. The authors also noted that the number of axles seemed to affect the acceleration performances.

In addition, the drivers commented that the quality of the crossing surface was a major factor in selecting the transmission ratios and crossing speed. Many drivers said that most crossings had a poor surface, which meant that they tended to cross them at substantially lower speeds so as not to damage their vehicle.

Although no tests were done with tanker trucks containing high-density liquids, the authors mentioned that carrying such products in tanks designed for other types of liquids could be a serious concern for drivers. When a tank is designed for a low-density product, using it to carry higher density products means that it cannot be filled completely in order to comply with weight regulations. Accelerating creates a wave effect in the load when changing gears, which can seriously affect the acceleration and control of a vehicle.

Finally, the authors also made a few observations with respect to drivers. First, they identified three types of drivers: owner-operators, those who leased vehicles, and those who worked for a transportation company. They noted a few differences in behaviour between these three types of drivers. Those who owned their own vehicles tended to be careful with the mechanics, those who leased their vehicle tended to accelerate more quickly, while those who worked for a transportation company complied with the company's policies.

With regard to company policies, some drivers said that the policies sometimes affected their safety when crossing railway lines. In particular, one company policy required vehicles to come to a full stop at passive crossings, prohibited a change of gear and limited the engine speed to 1600 rpm. In addition, this company checked driver conduct through the use of an onboard recorder. The company policies were felt to be dangerous in situations where a train could reach a crossing at approximately the same time as the heavy vehicle.

This last study did not relate the acceleration times of the vehicles to their operating criteria. However, the laws of dynamic physics make it possible to develop the following equation to precisely describe the acceleration of heavy vehicles:

$$Acceleration = \frac{\left(\frac{C * R}{Radius}\right) - Fr - Fa - mg * \sin(\alpha)}{Effective\_mass}$$

where: *C*: engine torque
R: reduction ratio (transmission and differential)
Radius: wheel rolling radius
Fr: roll resistance force
Fa: aerodynamic resistance force
α: grade angle
Effective mass: vehicle mass multiplied by a factor compensating for the rotating components

At first, this model seems simple, but it is actually a complex differential equation that must be solved with numeric methods. In this equation, the engine torque depends on the engine speed, the transmission ratio is variable, and the roll and aerodynamic resistance forces depend on the vehicle speed.

A simplified model was developed by Gillespie for acceleration at low speeds and without gear changes. This model is described by the following equation:

$$Tc = \frac{0.682\,(Lhz + Lt)}{Vmg} + 3.0$$

where: Tc: crossing time
Lhz: length of hazard zone (ft.)
Lt: length of vehicle (ft.) and
Vmg: maximum speed reached in the ratio used, this speed being determined by $V_{mg} = 60 / gr$, where gr is the total reduction ratio

In this model, the effect of grades can be introduced by multiplying Tc by the factor Fg determined by Gillespie, as presented in Table 15.

Table 15 – Grade Factor According to Gillespie (Harwood, 1990)

Grade (%)	3-5	6-10	11-13
Fg	1.26	1.47	1.78

This equation gives the results in Table 16 for the crossing times for different clearance distances for a 19.8 m vehicle.

Table 16 – Results of Gillespie's Equation for a 19.8 m Tractor-Trailer (Harwood, 1990)

Percent grade	V_{mg} (mi/h)	Length of hazard zone (ft)									
		30	40	50	60	70	80	90	100	110	120
0-2	8	11.1	11.9	12.8	13.7	14.5	15.4	16.2	17.1	17.9	18.8
3-5	6	13.8	14.9	16.1	17.2	18.3	19.5	20.6	21.8	22.9	24.0
6-10	5	16.0	17.3	18.7	20.0	21.4	22.8	24.1	25.5	26.9	28.2
11-13	4	19.2	20.9	22.6	24.3	26.0	27.7	29.4	31.1	32.8	34.5

Note: 1 mi = 1.61 km
1 ft = 0.305 m

In 1986, Gillespie conducted his own acceleration tests with 77 tractor-trailers and compared them with his model. He obtained the following results:

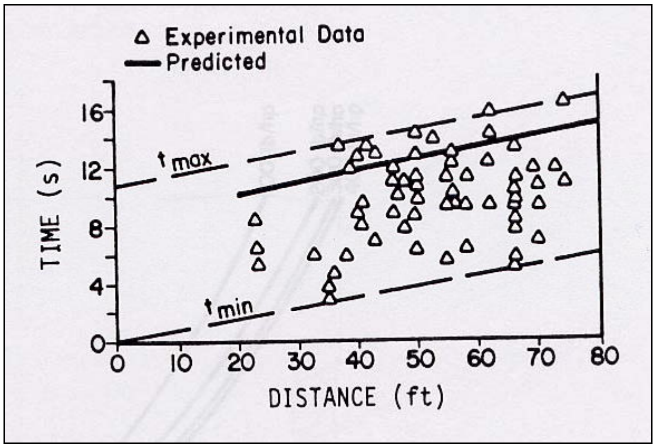


Figure 7 – Results of Gillespie's Tests (Harwood, 1990)

These results allowed him to state that his model tended to be rather conservative and he was also able to determine the equations for the maximum and minimum crossing time values:

$$T_{min} = 0.075\ (L_{hz} + L_t)$$

$$T_{max} = 10.8 + 0.075\ (L_{hz} + L_t)$$

Other acceleration tests were conducted by Hutton in 1970. He evaluated the acceleration criteria of 31 combinations of tractor-trailers, most of which were cab over engine tractors pulling two trailers of 8.2 metres in length. The power of the trucks varied between 228 hp and 375 hp, and the weight was between 15,100 kg and 40,900 kg (33,250 lb to 89,900 lb). He grouped his results according to the weight/power ratio for 100 lb/hp, 200 lb/hp, 300 lb/hp and 400 lb/hp. Figure 8 shows the acceleration curves found in the experiments for these 4 ratios.

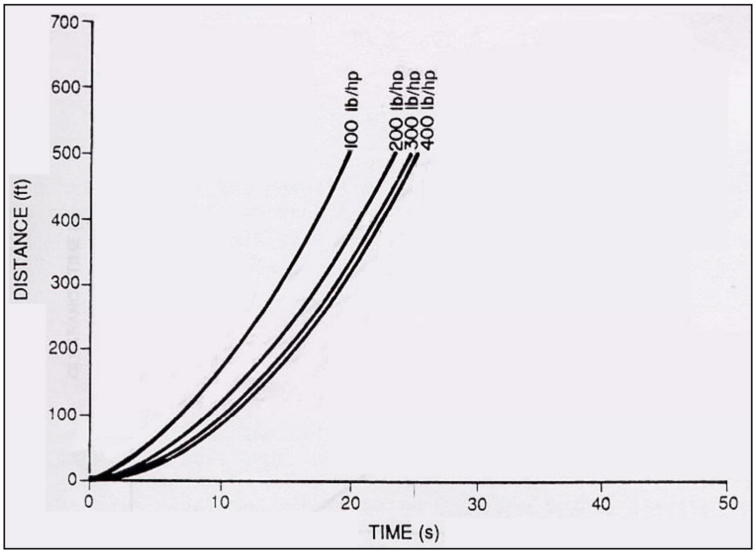


Figure 8 – Results of Hutton's Tests (Harwood, 1990)

The author was then able to determine the analytical equations for these curves. They are shown in Table 17.

Table 17 – Hutton's Acceleration Equation (Harwood, 1990)

Weight/Power ratio (lb/hp)	Crossing Time (sec)
100	$-6+\sqrt{36+1.25 \text{ x Distance covered}}$
200	$-3.2+\sqrt{10.2+1.40 \text{ x Distance covered}}$
300	$-1.9+\sqrt{3.8+1.40 \text{ x Distance covered}}$
400	$-0.6+\sqrt{0.4+1.25 \text{ x Distance covered}}$

These results were compared with the Gillespie model, as shown in Figure 9.

It can be seen that Gillespie's equation is conservative and that Hutton's curves are within the limits determined by Gillespie's tests. Similarly, it can be seen that most of the results show crossing times exceeding the 10-second minimum prescribed by the standard.

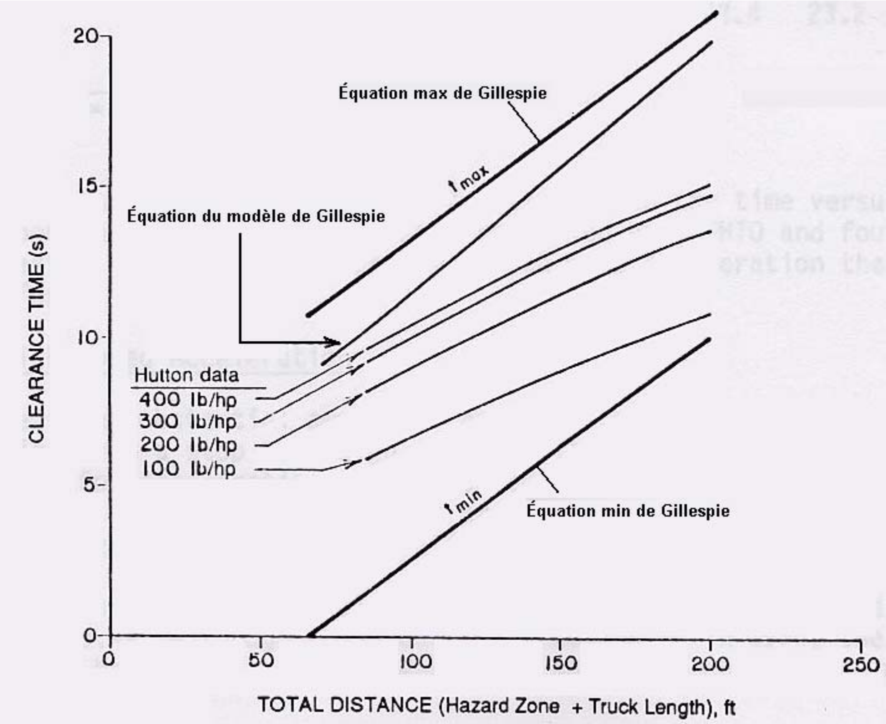


Figure 9 – Comparison Between Gillespie's and Hutton's Results (Harwood, 1990)

1.4.2 Braking

RTD 10, the *Geometric Design Guide* and the *Green Book* (U.S. equivalent of the *Geometric Design Guide)* from AASHTO (American Association of State Highway and Transportation Officials) all use the same formula to calculate the stopping sight distance. They are:

Braking distance [ft] = V^2 [mi/h] / 30*fs (imperial system)

Braking distance [m] = V^2 [km/h] / 254*fs (international system)

Where the prescribed coefficients of friction (fs) are shown in Table 18.

Table 18 – Coefficients of Friction Prescribed by RTD 10 (Table 4.4 in RTD 10)

Maximum Road Operating Speed (km/h)	Coefficient of Friction (f)
30	0.40
40	0.38
47 – 50	0.35
55 – 60	0.33
63 – 70	0.31
70 – 80	0.30
77 – 90	0.30
85 – 100	0.29
91 – 110	0.28
98 – 120	0.28

These standards propose a corrected formula when the road has a grade:

Braking distance = V^2 [mi/h] / 30*(fs+G) (imperial system)

Braking distance [m] = V^2 [km/h] / 254*(fs+G) (international system)

Where G: Grade % / 100

To obtain the stopping sight distances, the distance covered during the perception-reaction time must be added to the braking distance, which is usually acknowledged to be about 2.5 seconds. These standards thus propose the following formula for the distance to add to the stopping sight distance:

Distance to add = 1.47 × Perception-reaction time × Speed

From a dynamic point of view, these equations are all valid, but the coefficients of friction suggested are taken from tests conducted over 50 years ago using vehicles with locked brakes on wet asphalt. It is likely that modern vehicles now offer better performance. However, many heavy vehicles cannot stop safely with locked brakes because of the risk of blow out, jack-knifing or trailer swing. To bring a heavy vehicle to a controlled stop, the braking distances are thus much longer.

For these reasons, the University of Michigan Transportation Research Institute (UMTRI) and the National Cooperative Highway Research Program (NCHRP) suggest using a coefficient of rolling friction that is calculated as follows:

$$Fr = fp*TF*BE*CE$$

where: fp: maximum coefficient of friction between the wheels and the road
TF: tire tread depth adjustment factor
BE: braking efficiency adjustment factor (typically between 0.55 and 0.59)
CE: driver braking control efficiency adjustment factor (varies between 0.62 and 1.00)

This equation and the values of the coefficients to use have all been determined in braking tests to evaluate the effect of the different parameters. The graphs in Figures 10, 11 and 12, and in Table 19, allow us to evaluate these test results.

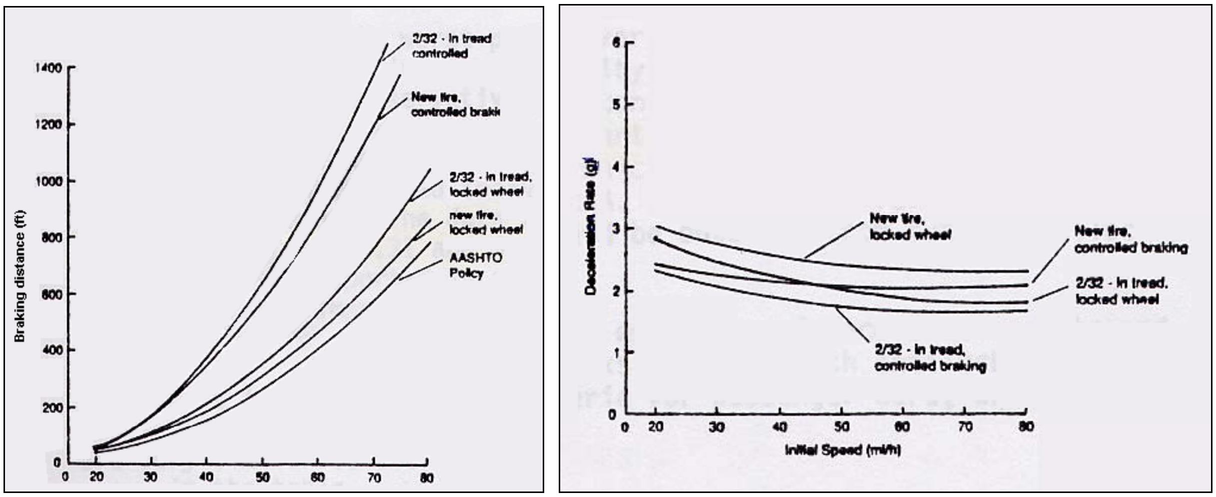


Figure 10 – Braking Distance Curves (ft) vs. Initial Speed (mi/h) from the NCHRP for Various Types of Braking and Tire Tread Depth (Harwood, 1990)

Table 19 – Braking Performances Identified in Tests by the NCHRP and UMTRI (Harwood, 1990)

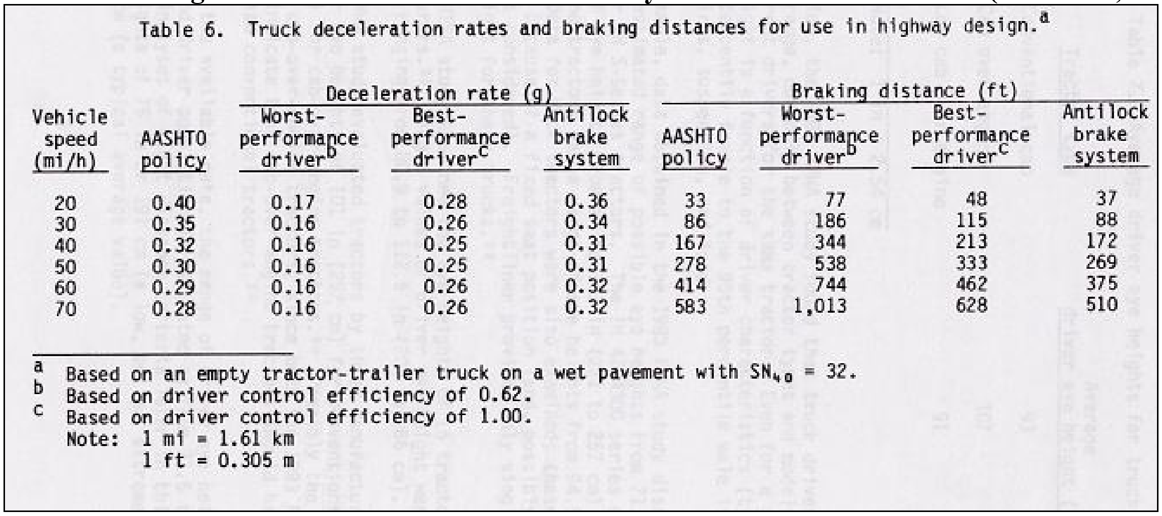


Table 6. Truck deceleration rates and braking distances for use in highway design.[a]

Vehicle speed (mi/h)	Deceleration rate (g)				Braking distance (ft)			
	AASHTO policy	Worst-performance driver[b]	Best-performance driver[c]	Antilock brake system	AASHTO policy	Worst-performance driver[b]	Best-performance driver[c]	Antilock brake system
20	0.40	0.17	0.28	0.36	33	77	48	37
30	0.35	0.16	0.26	0.34	86	186	115	88
40	0.32	0.16	0.25	0.31	167	344	213	172
50	0.30	0.16	0.25	0.31	278	538	333	269
60	0.29	0.16	0.26	0.32	414	744	462	375
70	0.28	0.16	0.26	0.32	583	1,013	628	510

[a] Based on an empty tractor-trailer truck on a wet pavement with $SN_{40} = 32$.
[b] Based on driver control efficiency of 0.62.
[c] Based on driver control efficiency of 1.00.
Note: 1 mi = 1.61 km
1 ft = 0.305 m

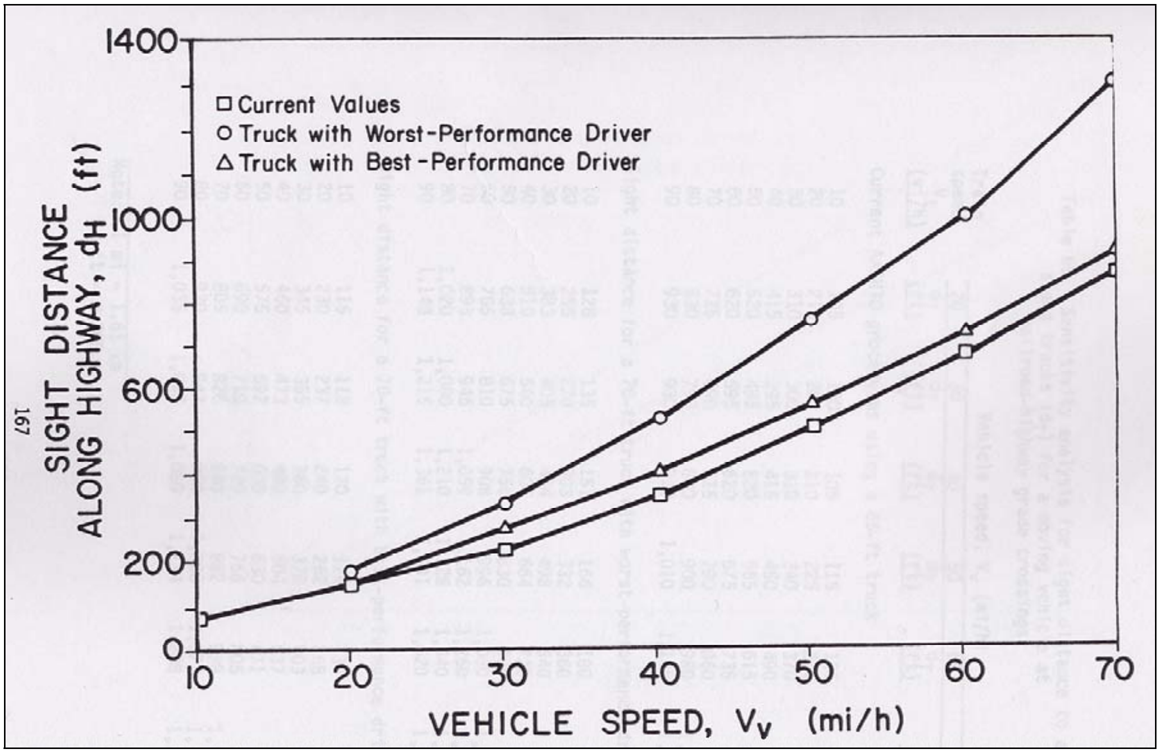


Figure 11 – Sight Distance Curves Along Highway vs. Heavy Vehicle Speed from the NCHRP (Harwood, 1990)

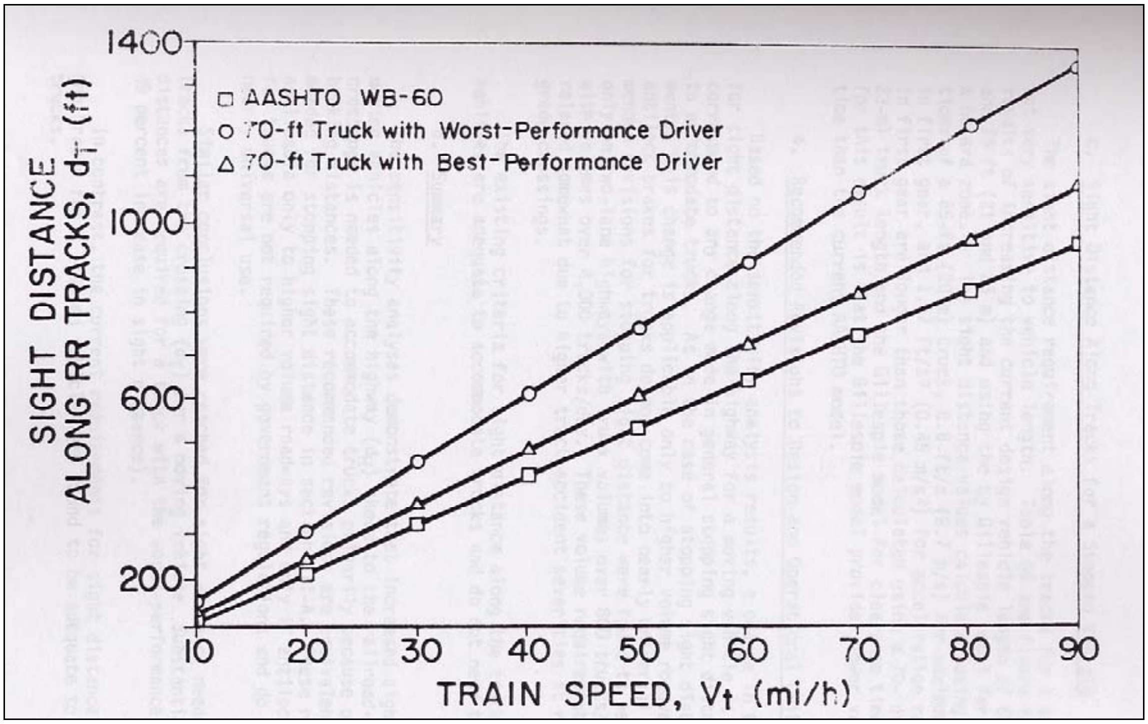


Figure 12 – Sight Distances Curves Along Tracks vs. Train Speed from the NCHRP (Harwood, 1990)

Note that the AASHTO values given are the same as those found in RTD 10 for automobiles.

After these tests, the two institutions determined that a driver with a 70% braking efficiency would be the most representative of all drivers on the road. The authors also derived the following formula to calculate TF (tire tread depth adjustment factor):

$$TF = 1 - \frac{\Delta fp\left(1 - \sqrt{x/n}\right)}{fp}$$

where: Δfp: difference between the coefficients of friction for a new tire and a completely used tire
x: remaining tread depth (use 12/32 inches if x ≥ 12/32 inches)
n: minimum depth ensuring a coefficient of friction equal to that of a new tire (this value is assumed to be 12/32 inches)

The braking performances of the heavy vehicles used by Harwood (1990) shown in Table 19 are the ones that seem the most realistic because they are relatively recent and present the results according to driver skill. Since the performances for the most skilled and experience drivers (best-performance drivers) can be controlled more efficiently, the quality and balance of the vehicle when braking are very useful references.

1.4.3 Recommendations

The various studies that were examined in this review of the literature made several recommendations for improving safety at grade crossings. The most significant ones can be grouped into technical recommendations and recommendations involving human factors.

1.4.3.1 Technical aspects

First, many studies suggested that the safest and most effective way of eliminating the risk of collisions at crossings was to put them on separate levels (underpasses/overpasses). Although this method is the most effective, it is very expensive and not always the best approach. Other methods that can improve safety at grade crossings are the installation of gates at active crossings, and turning passive crossings into active crossings with warning lights. These methods are less expensive than underpasses or overpasses, but their application must be cost-effective and suitable for the road and rail traffic at the crossing (Caird, J.K. et al. 2002).

At a passive crossing with no mandatory stop, a sight triangle is required to ensure crossing safety from a technical aspect. As mentioned above, this is based on the stopping sight distance, which is the side of this triangle along the road, and the distance that the train travels at a constant speed along this sight distance during the crossing time, plus the crossing clearance distance and the length of the vehicle. This last distance is the side of the triangle along the tracks. As can be expected, the stopping sight distance increases with speed, while the crossing time from this distance decreases with an increase in speed. John A. Read conducted certain tests in order to minimize the sight triangles. The tests allowed him to conclude that for the majority of road vehicles, the area of the sight triangle could be minimized for heavy vehicles with an approach speed between 40 km/h and 50 km/h. He thus suggests that at passive crossings without a mandatory stop, the speed limit be set to 50 km/h to minimize the area to clear for the sight triangles (Read, J.A., 1995).

Many references also suggest adding speed limit signs at several points before crossings given that they have been designed for a specific reference speed and that vehicles travelling faster or slower than this speed limit are open to a greater risk of collision, particularly long and heavy vehicles (Caird, J.K. et al. 2002).

Since many people are not very familiar with grade crossing design methods, there are very few who know the exact limits of the sight triangle when using passive crossings. In cases where these lines are much greater than the design values, some people could misjudge the proper actions to take if they see a train. John A. Read (1995) thus suggests placing signs to mark the edges of the sight triangle and sightlines along the tracks to avoid confusion.

Furthermore, many references, such as J.K. Caird, suggest using a stop sign at passive crossings where it is impossible to clear a sight triangle. This method is already used at many crossings. However, this alternative should not be used unless a sight triangle can really not be cleared, because the Kendall and Morrissette study showed that heavy vehicles required more time to clear a crossing from a full stop than at a constant speed.

Caird also suggests lighting active crossings when a train is present and lighting active crossings at all times. Given what happened on 19 December 2000 at Imperial Mills, Alberta (TSB report R00C0159, see section 1.2.1), this measure would no doubt have improved the safety at some crossings.

Caird (2002) also makes another recommendation regarding the arrival of a second train, and for which we have a very good example at Rivière Beaudette on 4 November 1994 (TSB report R94D0191). He suggests that a special warning system be installed at multi-track crossings with high rail traffic to warn of the arrival of a second train on an adjacent track when a first train is already at the crossing. This type of system has been tested in Northern Baltimore County in Maryland and has proven to be very effective [ref. 15].

In addition, as many other studies point out, D.W. Harwood et al. suggest increasing the crossing times for sight line design to accommodate heavy vehicles and to avoid having them reach a no option zone at crossings where drivers no longer have the time to brake nor the possibility of accelerating in order to clear the crossing safely.

1.4.3.2 Human factors

The various recommendations involving the human side of the problem of safety at grade crossings are primarily focussed on education, but also include the enforcement of existing laws. Some of the main recommendations identified in the literature are discussed below.

First, most of the sources that discussed the human side of the problem agree that there is a flagrant lack of education among drivers regarding knowledge of the inherent dangers of grade crossings. In fact, many drivers are very reckless about the fact that crossings are free of trains most of the time. These sources suggest increasing the awareness of road users to the dangers of grade crossings and suggest improving the visibility of the Operation Lifesaver program, which the public is hardly aware of at this time.

Many sources also state that the public does not know what attitude to take when approaching a grade crossing. Many users still tend to slow down when approaching a crossing, but despite the apparent safety of this attitude, it is actually riskier than travelling at the speed limit when approaching a crossing. These references suggest improving the content on grade crossings in driving courses and exams, and enhancing public awareness of the risk of travelling at speeds other than the speed limit at crossings (Read, J.A., 1995).

Naturally, some people also suggest improving the enforcement of legislation at crossings. Many methods have been suggested, such as increasing police presence at grade crossings. But it is not always advantageous nor economically viable to monopolize the time that police could use to solve other problems. Installing surveillance cameras that automatically issue traffic tickets to delinquent drivers has also been suggested. This type of device has been tested in several locations in the U.S., namely in Los Angeles where it has been very effective. However, this type of system is not yet socially accepted in Canada and it should not necessarily be used automatically [Ref. 14].

2. HEAVY VEHICLE ACCELERATION AND BRAKING TESTS

The whys and wherefores of heavy vehicle safety at grade crossings have now been clearly identified. Development of an adapted design and assessment tool should thus take them into account, but it should also be validated with the help of results from real heavy vehicle acceleration and braking tests. As mentioned earlier, not all of the test results currently used as a reference for design standards are properly adapted to existing heavy vehicles. With the help of the project monitoring committee, we identified the typical heavy vehicles and the grade crossings that represent the geometric limits allowed by current design standards. We then conducted three series of tests in the order listed below.

- Acceleration tests on dry asphalt surfaces over a maximum of 125 m, and on gravel roads over a maximum of 55 m;
- Braking tests at 90 km/h on wet asphalt surfaces;
- Acceleration tests from a stop line to the clearance point of nine typical grade crossings.

The tests were performed between 3 August 2002 and 11 February 2003 on the test tracks at the Centre de formation en transport routier (CFTR) of the Rivière du Nord school board, on the test tracks at PMG Technologies in Blainville, on eight railway crossings in the area between Blainville and St-Jérôme, and on one railway crossing located in a logging area north of La Tuque. The data acquisition system used for all the tests, a Racelogic Velocity-Box, is a very accurate device that uses GPS technology.

An interim report presented in November 2002 discusses the progress of all the test procedures, precisely identifies the criteria of the test vehicles used, gives a description and plans of the sites used, and presents the detailed results of the acceleration and braking tests performed. The sections below provide a general summary.

2.1 Test vehicles

To conduct the tests, the CFTR made its fleet of road vehicles available for our use. This fleet of 58 tractors, 5 straight trucks and 67 trailers of various types provided us with a very large choice for selecting the test vehicles. In order to choose the best range of vehicles that most closely represented the composition of heavy vehicle traffic on Canadian roads, we defined a number of significant criteria which we then used to make our selection of the vehicles used in the tests. These criteria were chosen because they have the most effect on vehicle acceleration and brake performances. In general, they included engine horsepower, the number of transmission ratios, the number of axles and the gross vehicle weight. Since the tests needed to be representative of the performances that can be obtained on the road, the test vehicles were loaded to their full legal capacity in order to measure their worst performances.

To ensure that our choice of criteria actually resulted in the worst performances, we randomly chose four vehicles of the same type (3-axle tractor and 2-axle trailer) but equipped with different mechanical components, engines and transmissions to study the effect of engine horsepower and transmission ratios only on the results. In addition, because the transport of high-density liquids in noncompartmentalized tanks causes specific problems (in particular the movement of the liquid during acceleration), we used two noncompartmentalized tanker trucks, a 6-axle tractor-trailer and a B truck-train supplied by Brasseur Transport and filled with water to the legal capacity of the tanks. No A or C truck-trains were selected because they are rare on our roads, and since they have the same number of axles as B truck-trains, there was no reason to believe that the performances of these vehicles would be different from B truck-trains. We also chose a school bus, supplied by Autobus Paquette, an intercity bus, supplied by Autocar Chartrand, and a logging tractor-trailer, for a total of 21 heavy vehicles. Vehicles used for forestry are different in that they have a very high gross weight and are oversized, thereby presenting an interest for this study because grade crossings can be found on some logging roads.

2.2 Acceleration tests

Acceleration tests on the track were conducted with almost all the test vehicles. Some preliminary acceleration tests were conducted by Alain Côté, our test driver, with various test vehicles to allow him to familiarize himself with the vehicles and the testing procedure. The preliminary tests also made it possible to establish the acceleration method used. We chose an acceleration method using progressive ratio changes, where the maximum engine speed at each ratio change is gradually increased. For instance, shifting from the first to the second ratio is done at an engine speed of 1250 rpm, shifting from the second to the third ratio is done at 1350 rpm, shifting from the third to the fourth is done at 1450 rpm, and so forth. Naturally, depending on the engine and transmission ratio criteria, the gear shifting method can vary slightly from one vehicle to another. This is the method normally used by heavy vehicle drivers because it allows for better energy efficiency, meaning that it reduces fuel consumption with only a very minimal effect on vehicle acceleration performance. The preliminary tests were also done using two other gear shifting techniques that were not retained because they were not sufficiently representative of normal usage. The two techniques were maximum acceleration, i.e., tests done by changing ratios at the highest engine rpm, and acceleration using all gears including half gears. In reality, on relatively level terrain, heavy vehicle drivers equipped with an 18-speed transmission, even when fully loaded, use only their nine main gears since the others are half gears used only on grades.

Acceleration tests with gear shifting were conducted with all the test vehicles except the two buses, which were equipped with automatic transmissions. Acceleration tests without gear shifting were also conducted on several vehicles in order to evaluate the impact of provincial regulations prohibiting the shifting of gears while crossing railway tracks. As allowed by legislation, the gear changes were done in the first 5 m of acceleration (i.e., the distance covered before reaching the first rail of the tracks). For each of the test vehicles, only one gear change was possible in this very short distance. The presence of tracks in poor condition was also simulated in order to measure this effect on acceleration performances, since drivers tend to slow down or stop accelerating to avoid discomfort and damaging their vehicle. We simulated the presence of railway tracks and a crossing surface in poor condition by nailing 2x3 (1½ in. x 2½ in.) planks into the road for the tests on gravel.

Acceleration tests for clearing typical grade crossings (site tests) were then conducted with the longest and heaviest vehicles in each category: a straight truck, a tractor-trailer and a truck-train. In addition, a tractor-trailer used for logging and heavily loaded with tree-length wood was tested at a logging site. The method that used progressive ratio changes was also used. For crossings on a grade and those that were not horizontal over the entire acceleration distance, tests were done in both directions. The acceleration distances used are the sum of the grade crossing clearance distance and the length of the test vehicle. At one of the test sites, an intersection at 30 m was also simulated to evaluate the effect of the intersection. The presence of an intersection after a grade crossing can affect the crossing time, especially for long vehicles, since the drivers have to stop accelerating before they have completely cleared the crossing. A number of acceleration tests without gear changes were also conducted at the test sites.

The results obtained are presented as acceleration curves showing the acceleration or crossing time in relation to the distance covered. For accelerations on an asphalt surface, the time required to cover a distance of 125 metres varies from 15 to 43 seconds, depending on the type of vehicle used and the gear shifting method. For the tests on gravel simulating a crossing surface in poor condition, the results show that this factor has a definite impact on the crossing time, as shown in Figure 13.

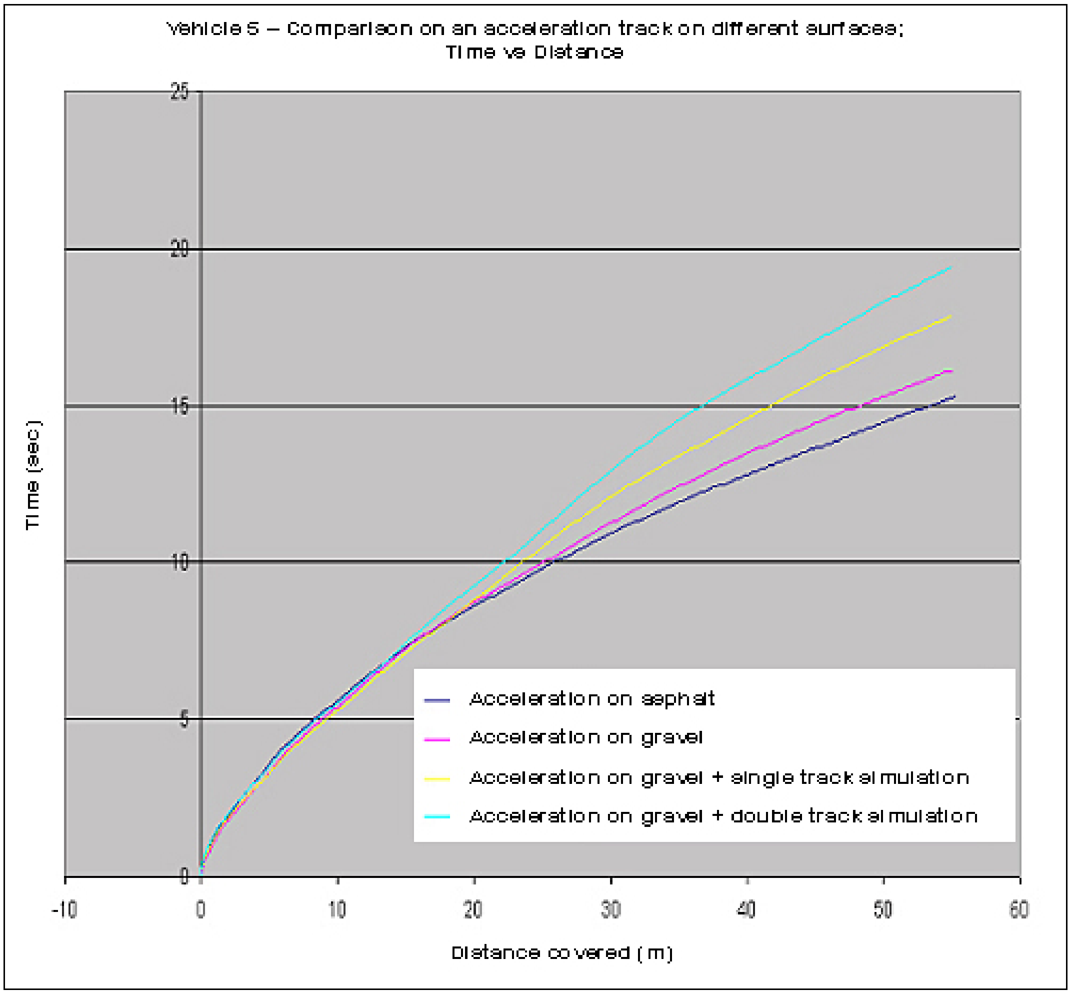


Figure 13 – Comparative Acceleration Curves on Asphalt and Gravel Surfaces, and Simulating a Crossing with a Poor Surface

Figure 14 illustrates the comparative results on site for a tractor-trailer crossing the tracks with and without changing gears. The results clearly indicate that the crossing time is significantly longer when drivers are prohibited from changing gears.

An example of the comparative results with and without an intersection at 30 metres for a truck-train using a crossing is shown in Figure 15. This simulation of an intersection was set up to represent the most critical scenario under current standards. At a crossing with two sets of tracks, there is a difference of about one second in the crossing time.

Table 20 presents the results of all the site tests. The crossing time varies from about 7 to 18 seconds, depending on the type of vehicle used and the geometry of the tracks.

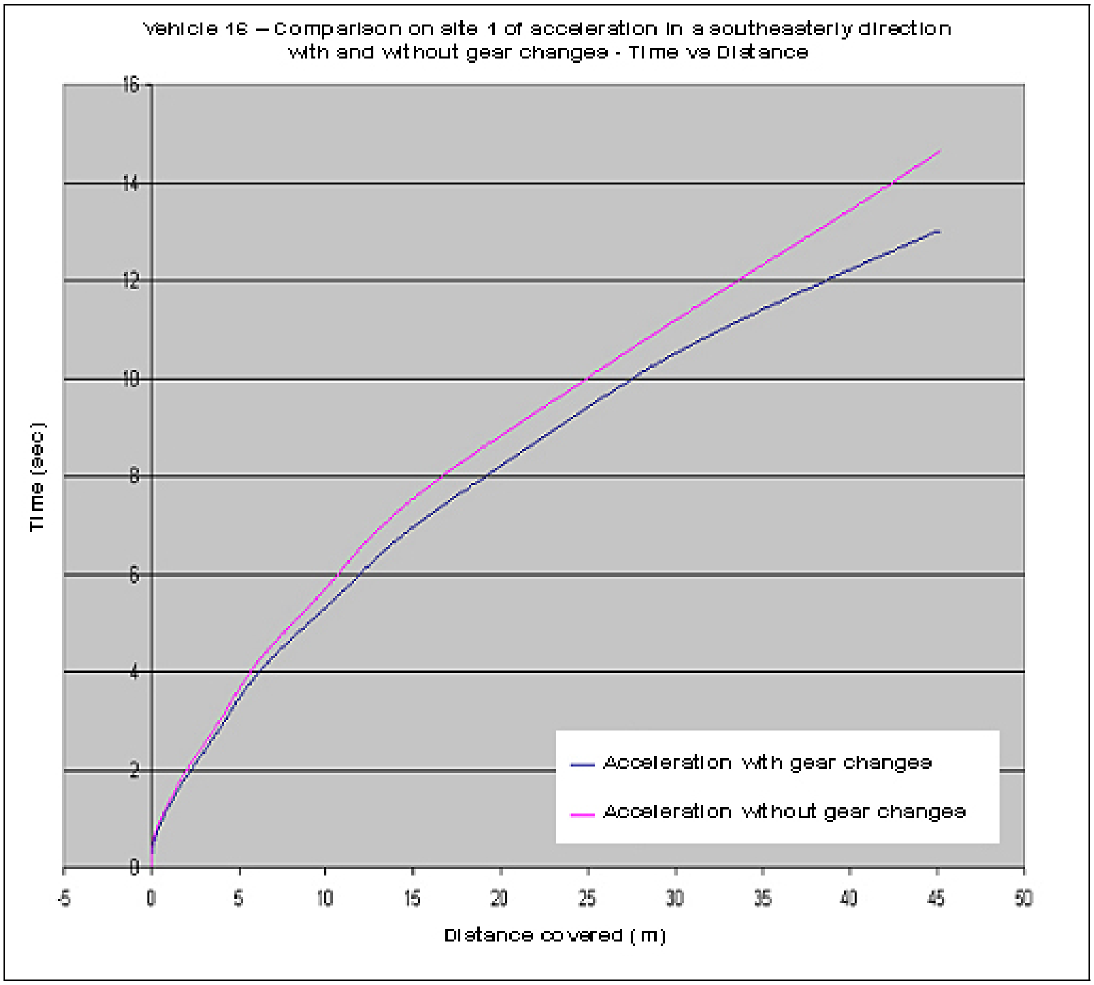


Figure 14 – Example of Acceleration Curves on Site for a Tractor-trailer With and Without Gear Changes

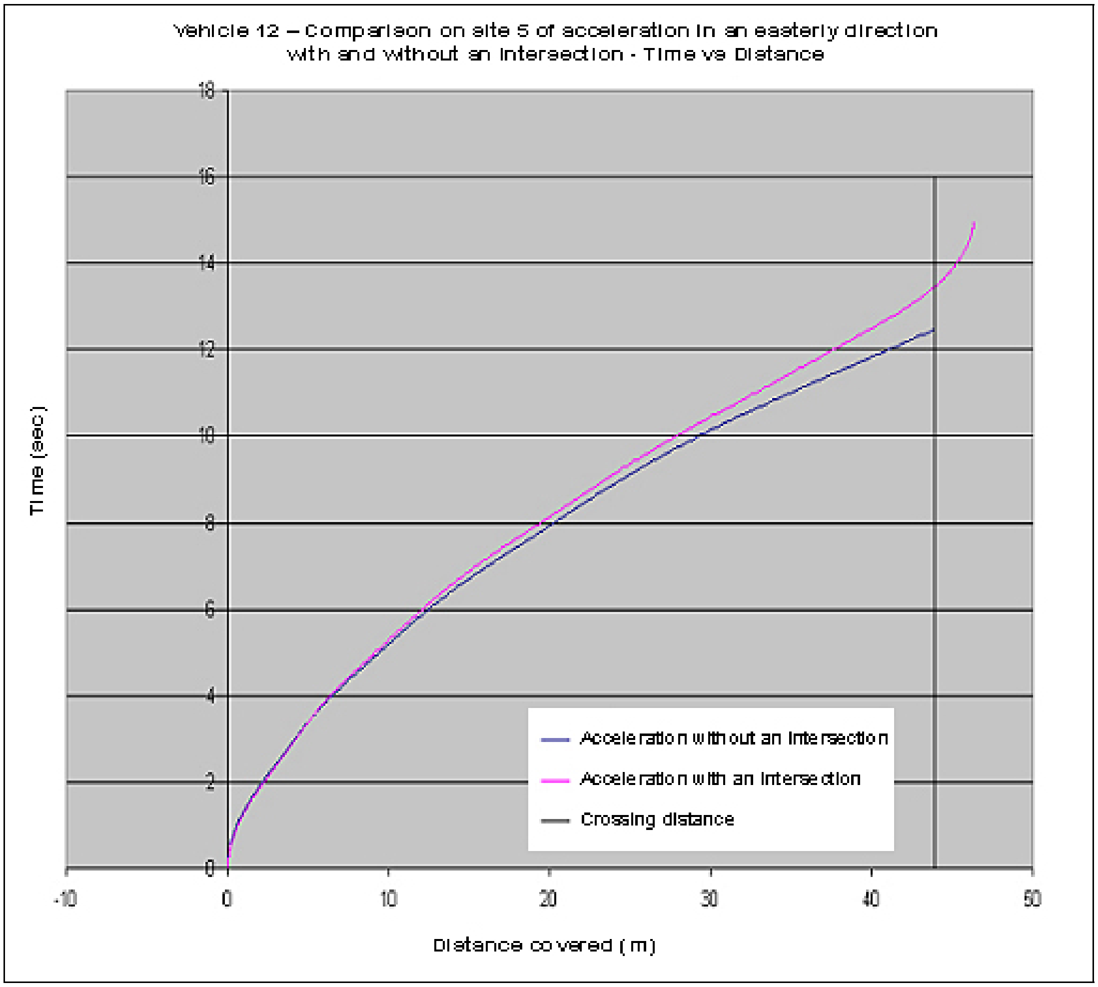


Figure 15 – Comparative Results for a Truck-train With and Without an Intersection at 30 Metres

Table 20 – On Site Acceleration Test Results
[Vehicle crossing times at the test sites]

	Crossing Time (seconds)			
	Clearance Distance	**Vehicle 2**	**Vehicle 12**	**Vehicle 16**
Site 1 – SE direction	25 m	10.41	15.26	13.04
Site 1 – SE direction – No shifting	25 m			14.65
Site 2 – NW direction	11.4 m	8.14	13.93	11.88
Site 2 – NW direction – No shifting	11.4 m			12.43
Site 2 – SE direction	11.4 m	6.83	11.31	9.48
Site 3 – NE direction	9.1 m	7.08	17.71	9.82
Site 4 – NE direction	9.1 m	7.00	11.26	9.95
Site 5 – E direction	19.4 m	9.11	12.47	11.41
Site 5 – E direction – Intersection	19.4 m	9.10	13.55	11.90
Site 5 – W direction	19.4 m	9.28	13.57	12.09
Site 6 – NNE direction	15.8 m	7.01	10.62	9.45
Site 6 – SSW direction	17.3 m	8.16	14.63	11.70
Site 7 – NE direction	13.4 m	8.02	12.50	11.20
Site 8 – N direction	39.6 m	12.58	16.44	16.01
Site 8 – S direction	39.6 m	12.50	16.14	15.40

2.3 Braking tests

To be able to trace the sight triangles from the stopping distances of the heavy vehicles, braking tests were conducted on wet asphalt (a standard road design condition in Canada) from an initial speed of 90 km/h. The results of the tests at this speed can then be interpolated easily for all lower speeds. Obviously, these results do not take into account the distances travelled during the perception and reaction times, which must then be added to obtain the real braking distances. Since braking performance is affected only by the weight of the vehicle and its distribution on the various axles, only six of the test vehicles were used in the braking tests: two tanker trucks, the two heaviest straight trucks, and the longest and heaviest tractor-trailer and truck-train. Because of the inherent dangers in these types of tests, they could not be done on site and were carried out on a closed track with no traffic at the PMG Technologies test centre in Blainville.

The results are presented as braking curves showing the distance travelled in relation to speed. Figure 16 shows the comparative results obtained for the six test vehicles. For the braking tests at 90 km/h on wet asphalt, the braking distances obtained varied from 67 to 116 metres, depending on the type of vehicle used.

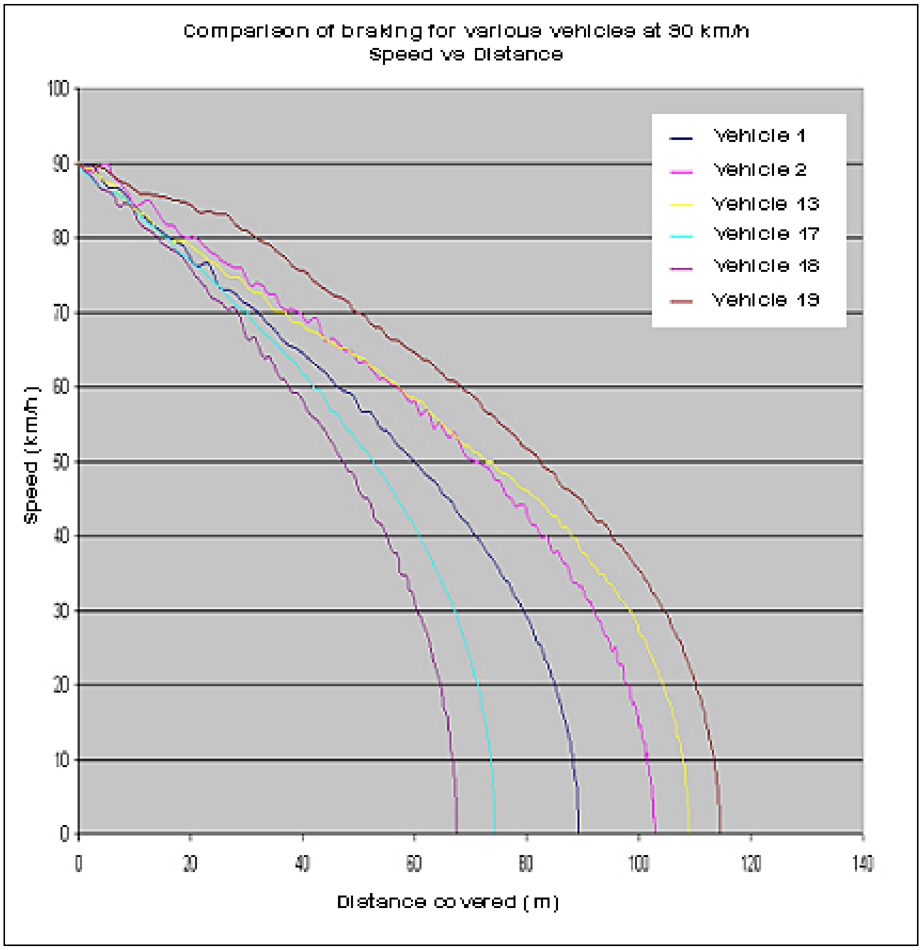


Figure 16 – Braking Curves of Various Test Vehicles on the Track

3. RESULTS OF DRIVER INTERVIEWS

During the period from June 2002 to April 2003, we interviewed close to 100 drivers of straight trucks, buses and tractor-trailers at random in Quebec regarding their actions when using crossings. Table 21 presents a summary of the responses.

Table 21 – Results of Driver Interviews Regarding Their Actions at Crossings

Acceleration method used at a crossing	Do you change gears when using a crossing?	Precautions taken when approaching a crossing
Identical to a normal intersection: **73%**	Yes: **52%**	Full stop: **48%**
Faster than at a normal in intersection: **3%**	No: **48%**	Check for a train: **62%**
Slower than at a normal intersection: **24%**		Listen for a train: **8%**
		Slow down: **14%**

As for the acceleration method used, most drivers (73%) accelerated the same way over a crossing as they would at a normal road intersection. However, a fairly high percentage of 24% of the drivers said they accelerated slower than normal when crossing railway tracks. This clearly illustrates that safety factors must be applied when calculating crossing time. Furthermore, with respect to the possibility of changing gears while crossing, more than half of drivers do so, even when provincial legislation prohibits this action. Finally, it is interesting to note that in the best case, only 62% of drivers said they took the precaution of visually checking whether a train was approaching the crossing. As mentioned in section 1.4.3.2, there definitely appears to be a lack of awareness and training for heavy vehicle drivers with respect to safety at grade crossings.

4. CREATING A GRADE CROSSING DESIGN AND ASSESSMENT TOOL

As mentioned earlier, the ultimate goal of the testing program and mathematical modelling is to produce a grade crossing design and assessment tool that can be integrated into the federal RTD 10 standard.

The grade crossing design and assessment tool must therefore allow the calculation of sight triangles adapted to the design vehicle selected, provincial legislation in effect, and the specifications of the grade crossing itself. To do this, a mathematical acceleration model must be developed from the test results, and the worst acceleration performances of the design vehicle classes must be established. Similarly, the braking performances of heavy vehicles must be determined according to the results of the braking tests conducted to permit the calculation of stopping sight distances. The final tool will also make it possible to determine warning times for active crossings.

4.1 Mathematical acceleration modelling

The model developed represents the acceleration of heavy vehicles according to their operating characteristics. To do this, a differential equation of movement for acceleration was used :

$$\text{Acceleration} = \frac{\text{Engine force} - \text{Drag force} - \text{Roll resistance force} - \text{Grade force}}{\text{Effective mass}}$$

where:

$$\text{Engine force} = \frac{\text{Engine torque} \times \text{Reduction ratio} \times \text{Efficiency}}{\text{Wheel rolling radius}}$$

$$\text{Drag force} = \underline{\text{Frontal surface} \times \text{Drag coefficient} \times \text{Air density} \times \text{Speed}^2}2$$

$$\text{Roll resistance force} = \text{Mass} \times 9.81\ \text{m/s}^2 \times \text{Rolling friction coefficient}$$

$$\text{Grade force} = \text{Mass} \times 9.81\ \text{m/s}^2 \times \sin(\arctan(\text{Grade}\ (\%)\ /\ 100\%))$$

$$\text{Effective mass} = \text{Mass} \times \text{Factor compensating for the rotating components}$$

The MATLAB software and the highly precise fourth order Runge-Kutta numeric resolution method were used to solve this equation. The operating criteria for the heavy vehicles used in this modelling include the engine torque curves (see Figure 17), transmission ratios, differential ratios, frontal surfaces, masses, lengths, number of wheels, rolling radii and inertia of the rotating components.

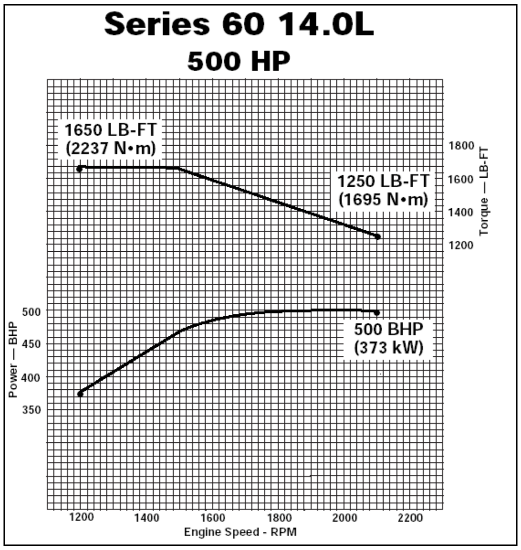
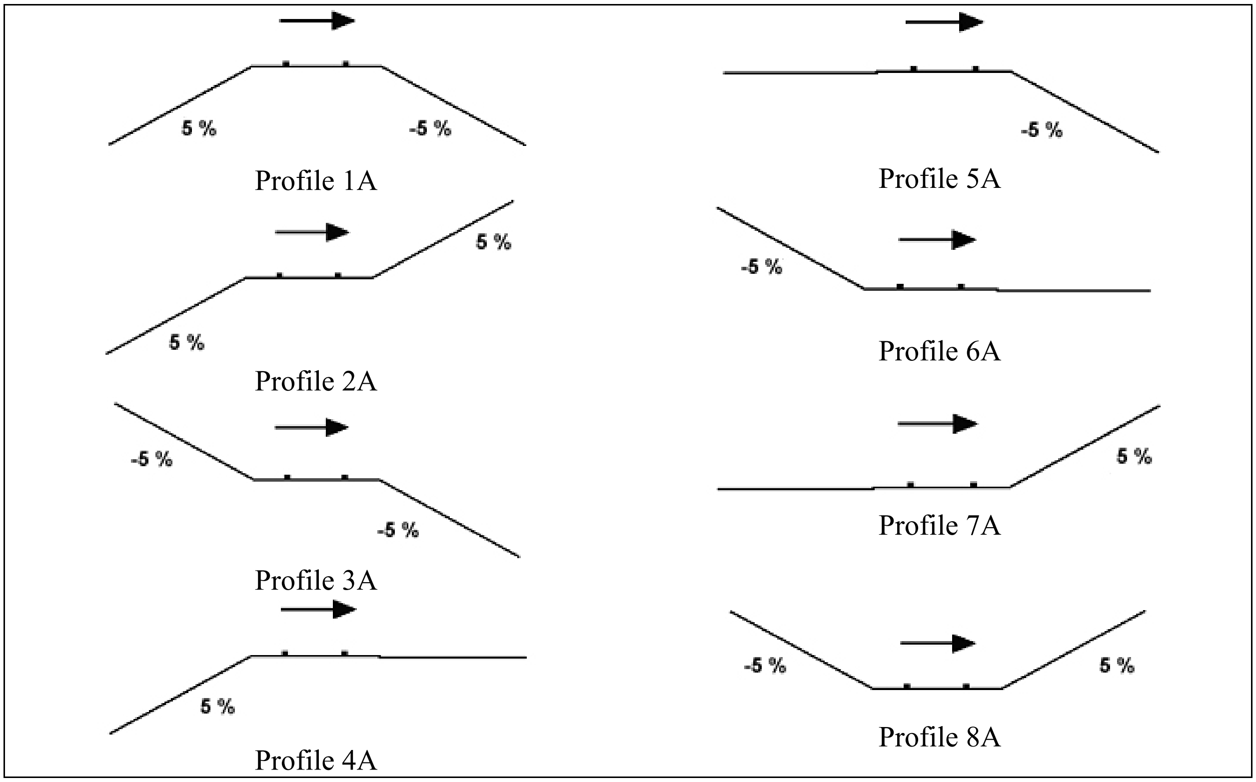


Figure 17 – Power and Torque Curves for a Detroit Diesel Series 60 14L 400 HP Truck Engine

The mathematical model was then validated using the results of the tests on the tracks. It was then possible to determine the various factors more precisely, such as the efficiency of the transmission ratios, ratio change times, engine power when changing ratios, coefficients of roll resistance on asphalt and gravel, and effective masses (wheel, brake and engine inertia).

The acceleration tests on site subsequently made it possible to validate the part of the mathematical model for the grade crossing criteria. These criteria are mainly the approach and departure gradients, the angle between the road and the tracks, and the condition of the crossing surface. A gradient function, validated by tests on site, was integrated into the model to take the profile of the grade crossing approach and departure profiles into account. In all, a total of 17 design profiles were established, ranging from a level crossing up to an uphill or downhill gradient of 5%, as proposed in RTD 10. The profiles for road gradients of 5% are presented in Figure 18. The level profile, the eight profiles in Figure 18 and these same profiles for 2% gradients represent all 17 proposed profiles.

Note that the gradient function in the model also causes the gear changing times to vary according to the severity and nature of the gradient. We observed that drivers change gears more rapidly on uphill slopes to minimize their loss of speed, and more slowly on downhill slopes because their vehicles accelerate due to the effect of the gradient. The driver-related operating criteria are determined for a driver with little experience. To do this, the gear changing times for our experienced test driver were multiplied by 50% in order to simulate a less-skilled driver. Typical gear changing times ranging from 1.5 to 3.0 seconds, depending on the gradient profile, were thus established as shown in Table 22. These times were validated by observing the gear handling performance of young heavy vehicle drivers with little experience. Consequently, they apply to the large majority of drivers, especially those who are less skilled or who only occasionally drive trucks with manual transmissions.



Profile 1A

Profile 2A

Profile 3A

Profile 4A

Profile 5A

Profile 6A

Profile 7A

Profile 8A

Figure 18 – Design Profiles Used in the Reference Graphs (Gradients of 5%)

Table 22 – Gear Changing Times According to Driver Skill

Gear changing time for a professional driver (test driver)	
Level terrain	1.5 seconds
Uphill slope of 5%	1.0 second
Downhill slope of 5%	2.0 seconds
Gear changing time used in the tool and simulating the performance of an inexperienced driver (performance of the test driver + 50%)	
Level terrain	2.25 seconds
Uphill slope of 5%	1.5 seconds
Downhill slope of 5%	3.0 seconds

The acceleration test results allowed us to identify four design vehicle categories (see Figure 19), which are buses, straight trucks, combination vehicles (tractor-trailers and truck-trains), and all non-standard logging vehicles. When compared with the RTD 10 vehicle classes in Table 8, classes 2, 3 and 4 can be grouped with the "straight" design vehicle, classes 5, 6, 7 and 8 can be included with the "combination" design vehicle, and 9, 10 and 11 can be included with the "bus" design vehicle.

Based on the strictest operating criteria, the worst operating performance for each class of vehicle was retained. These criteria are the gross weight and maximum length of the vehicles, and the coefficient of friction on a gravel road that takes the poor condition of the crossing surface into account.

In addition, the lengths of the design vehicles that must be used in the various calculations for the sight triangles are shown in Table 23.

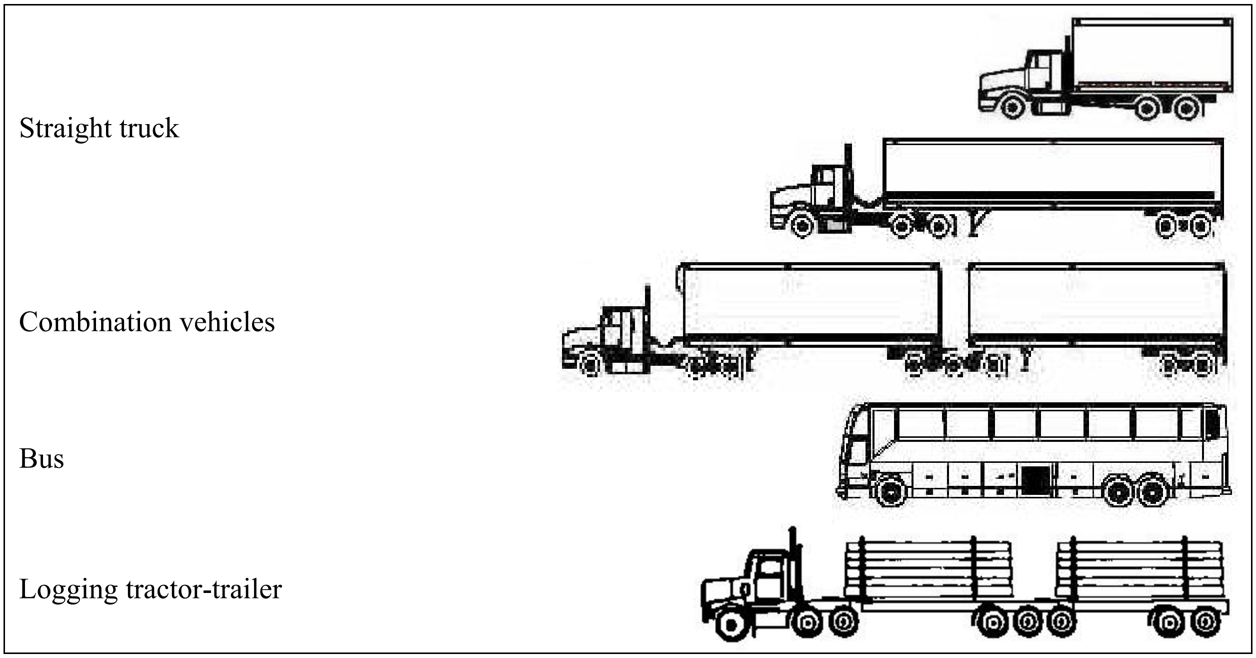


Figure 19 – Identification of Design Vehicles

Table 23 – Maximum Length of Design Vehicles

Design vehicle	Maximum length
Straight truck	12.5 m
Combination vehicle	25.0 m
Buses	18.5 m
Logging truck	29.0 m

4.2 Reference graphs for departure time calculations

The mathematical acceleration modelling makes it possible to produce reference graphs for departure times at grade crossings for stopped vehicles. Figure 20 shows an example of these reference graphs. The set of graphs developed for the 17 design profiles is contained in Appendix A of this report. Note that a number of profiles are grouped on the same graph, since the departure time performances were equivalent. These reference graphs are the first elements for the grade crossing design and assessment tool. They propose departure time to clearance distance ratios for grade crossings for each design profile and each design vehicle. Note that the curves include driver perception-reaction time and vehicle length. In addition, the graphs are based on the profiles of single-track crossings, a situation that our model has shown to be conservative. For cases where it is prohibited to change gears when crossing railway lines, separate graphs are proposed, hence there are two graphs per design profile.

For a crossing that is in very bad condition and where the rails are considerably higher than the crossing surface, we suggest using the reference graph produced for the case where changing gears is prohibited. This closely simulates the behaviour of a driver who, when clearing a crossing in very poor condition, tends not to accelerate when crossing the rails. Some other special conditions were established for tanker trucks (crossing time multiplied by a factor of 1.2) and when an intersection is located close to the crossing (driver perception-reaction time increased from 2.5 seconds to 4.0 seconds). These corrections were validated in the analysis of the acceleration test results. Table 24 summarizes the special conditions for using the graphs.

In addition, for each reference graph, design vehicles with very similar performances (difference of less than one second for acceleration up to a clearance distance of 100 metres) were included in the same category for the sake of simplicity. This means that for some design profiles, the performances of the logging vehicle class are included with those for combination vehicles. In addition, the performances of the bus design vehicle are not given for the graphs with no change in speed because vehicles with automatic transmissions are used as a reference.

Users of the tool must thus select a vehicle category, determine whether gear changing is prohibited (or if the crossing is in very bad condition), measure or determine the profiles in both directions at the crossing, and find the corresponding reference graphs. For profiles other than the ones proposed, the results must be interpolated linearly. Users determine the departure time in both directions at the crossing based on the clearance distance. With these departure times and the maximum train speed, they can determine the sightlines along the tracks in both directions of the road. Examples for use are presented in section 4.4.

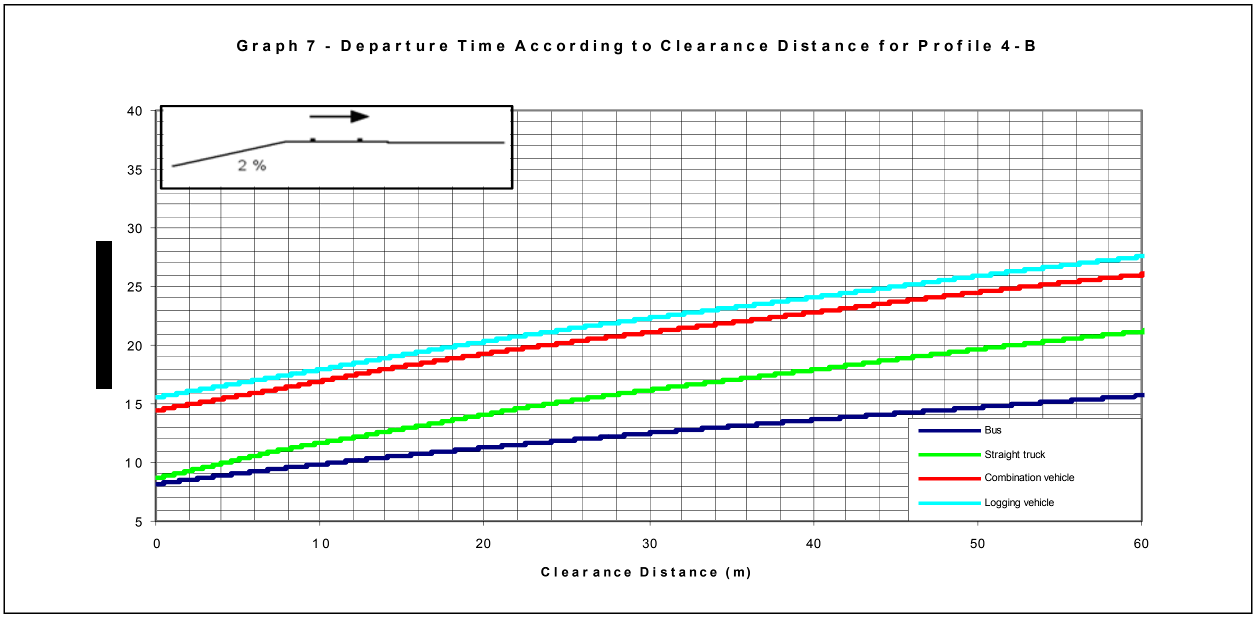


Figure 20 – Example of a Departure Time Reference Graph According to Clearance Distance and Design Vehicle

Table 24 – Special Conditions for Using the Reference Graphs

Special condition	Effect on departure time
Tanker trucks	Multiply by a factor of 1.2
Proximity of an intersection	Add 1.5 seconds to the departure time
Provincial prohibition from changing gears while crossing railway tracks	Use the graph with no change in gear
Crossing surface in very bad condition	Use the graph with no change in gear

4.3 Determining stopping sight distances

The braking test results help to determine the braking efficiency on a wet surface to be used when calculating the stopping sight distances. This involves identifying the typical braking performances of a heavy vehicle. To do this, we calculated the deceleration rates obtained in the braking tests for the six heavy vehicles tested (see section 2.3, Figure 16). The results of these calculations are presented in Table 25. Note that the decelerations vary from 0.277 g to 0.478 g.

Table 25 – Decelerations Obtained in the Braking Tests

Test vehicle	Decelerations obtained in braking tests
Straight truck, 2 axles	0.342 g
Straight truck, 3 axles	0.308 g
Tanker B train	0.277 g
Tractor-trailer, 6 axles	0.436 g
Tractor-trailer, 3 axles	0.478 g
Tractor-trailer tanker, 5 axles	0.299 g

It was impossible for us to identify a clear relationship between the number of axles, vehicle weight and deceleration rate. Consequently, as a reference we used the calculations for the worst deceleration rate obtained in the tests, which was 0.277 g. In addition, as proposed by Harwood (1990), we used a driver efficiency factor of 70% and a driver perception/reaction time of 2.5 seconds (see section 1.4.2).

Furthermore, in our calculations we also used an initial braking speed that is 10 km/h higher than the legal speed limit, so as to properly reflect the real traffic conditions of these vehicles. In fact, in our opinion, the sight triangle calculation method should consider heavy vehicle drivers travelling at speeds other than the posted speed limit. For instance, if a vehicle exceeds the posted limit, the driver will probably not have enough distance to stop if an approaching train is spotted. On the other hand, if a vehicle is travelling slower than the speed limit, which is not uncommon because many drivers tend to slow down at crossings, and the driver does not see a train while approaching the crossing, there is still a chance that a train can reach the crossing before the road vehicle. To deal with this problem, a safety factor must be used. We thus propose that the braking distance be calculated for a speed that exceeds the posted speed limit by 10 km/h, and that the crossing time from this distance be calculated for a speed limit that is 10 km/h slower than the speed limit.

As for calculating the stopping sight distances, we compared our results with those proposed in RTD 10 and those inspired by Harwood (1990). As shown in Table 26, these results are very similar. It should be noted in particular that the braking distances obtained from Harwood's data are the most conservative. Harwood's results are taken from braking tests conducted by two organizations, the University of Michigan Transportation Research Institute (UMTRI) and the National Cooperative Highway Research Program (NCHRP). The related stopping sight distances are obtained by using the deceleration rate linked to the performances of the best drivers ("Best-performance driver", see Table 19 in section 1.4.2), which is multiplied by 70% to account for the efficiency factor, and taking a driver perception-reaction time of 2.5 seconds into account. Since the results taken from Harwood are the most conservative, we will use them in developing the grade crossing design tool. The stopping sight distances thus obtained are representative of most heavy vehicle drivers, and also take into account the mechanical condition of the braking system of most heavy vehicles, which is not always excellent.

Table 26 – Comparison of Stopping Sight Distances According to Harwood (1990), RTD 10 and Our Test Results

Speed Limit (km/h)	Sight Distances (m)		
	Harwood x 70 %	RTD10	Our Results x 70%
20	39	XXX	39
30	60	XXX	60
40	85	70	85
50	119	110	115
60	154	130	148
70	199	180	185
80	245	210	227
90	294	265	272
100	348	330	322

The second part of the tool consists of Tables 27 and 28, which make it possible to determine the stopping sight distances according to the legal speed limit of the road and its profile, as well as the presence of anti-lock brakes (ABS) on vehicles using the crossing. In fact, using the braking distances obtained by Harwood (1990) with vehicles equipped with ABS brakes allowed us to establish a specific table that could be used for crossing design or assessment when all commercial vehicles are equipped with ABS systems. Two examples of use of the tool are presented in the next section.

Table 27 – Stopping Sight Distances Based on the Speed Limit for Heavy Vehicles with Conventional Brakes

Conventional Braking System (70% Efficiency)						
Speed Limit (km/h)	Coefficient of Friction (g)	Stopping Sight Distance (m)				
		5%	2%	Level	-2%	-5%
20	0.196 (0.28 x 70%)	35	37	39	41	45
30	0.196 (0.28 x 70%)	53	57	60	64	71
40	0.196 (0.28 x 70%)	75	80	85	91	102
50	0.182 (0.26 x 70%)	103	112	119	129	149
60	0.182 (0.26 x 70%)	132	144	154	168	195
70	0.175 (0.25 x 70%)	167	185	199	218	257
80	0.175 (0.25 x 70%)	204	226	245	268	317
90	0.175 (0.25 x 70%)	244	271	294	323	384
100	0.175 (0.25 x 70%)	288	320	348	383	457

Table 28 – Stopping Sight Distances Based on the Speed Limit for Heavy Vehicles with ABS Brakes

ABS Braking System						
		Stopping Sight Distance (m)				
Speed Limit (km/h)	Coefficient of Friction (g)	5%	2%	Level	-2%	-5%
20	0.36	29	30	31	31	32
30	0.36	43	44	45	46	48
40	0.36	59	61	62	64	66
50	0.34	78	81	83	86	90
60	0.34	98	102	105	109	115
70	0.31	125	132	137	142	152
80	0.31	151	159	165	172	185
90	0.31	179	189	196	205	221
100	0.31	209	221	230	240	259

4.4 Examples of use of the tool

In order to properly illustrate the methods for using the proposed tool, two examples of grade crossings for which the sight triangles, warning time and gate descent time (if it is an active crossing) are to be checked are presented in this section.

The first railway crossing analysed is a passive crossing where the road lies north-south and the single track is at an angle to the road. When heading north, the approach to the crossing has an upward gradient of 3% while the road surface on the other side is level. There are no mandatory stop signs at this crossing and the posted speed limit is 90 km/h. The crossing distance is 19 metres in the northward direction and 17.5 metres in the southward direction. The crossing surface is also in poor condition. Furthermore, this is a crossing that many tractor-trailer tankers carrying dangerous materials use every day.

The second crossing analysed is an active crossing with flashing lights and gates on a road that lies east-west. The two railway tracks at the crossing are perpendicular to the road. The crossing approach going west has a downhill gradient of 1%, while the other side of the crossing has an uphill gradient of 4.5%. The posted speed limit is 50 km/h and provincial regulations permit the changing of gears when crossing railway tracks. In addition, in the east and west directions, the crossing distances are the same at 23 metres. The crossing surface is in good condition. The crossing is in an urban area and is used primarily by straight trucks carrying general merchandise.

4.4.1 Calculating the sight triangle when stopped

In the first instance, the sight triangle when stopped is calculated for the first passive crossing. The reference graphs with no change in gears are used because the crossing surface is in poor condition, and the design vehicle is a "combination vehicle". Heading north, profiles 4B (2%) and 4A (5%) are used. Corresponding reference graphs 7 and 6 in Appendix A give 19 metres for crossing times of 19.5 seconds and 21 seconds, respectively. Since the approach gradient is 3%, the corresponding time for the road gradient is interpolated as follows:

$$\frac{x - 19.5}{21.0 - 19.5} = \frac{3\% - 2\%}{5\% - 2\%}$$

$$x = 20.0 \text{ seconds}$$

This time must then be multiplied by 1.2 to account for the tanker trucks that use the crossing. The departure time going north is thus 24.0 seconds.

The same process must be followed to calculate the departure time when heading south. Profiles 5B (2%) and 5A (5%) are then used. Corresponding reference graphs 12 and 13 in Appendix A give 17.5 metres for identical crossing times of 18.0 seconds. It is thus not necessary to interpolate the time for the road gradient of 3%. As for the other direction, the departure time is simply multiplied by 1.2 to account for the tanker trucks that use the crossing. The departure time going south is thus 21.6 seconds.

Finally, based on these two departure times and the maximum speed of the trains using the tracks, the sight distances along the tracks ($D_{stopped}$) are calculated in both directions on the road. These results give the stopping sight triangles.

In the second instance, the departure times are calculated for the active crossing. In fact, we will need these results for calculating the warning time for this crossing. The reference graphs with a change of gear are used, because the crossing surface is in good condition and provincial regulations permit the changing of gears. The design vehicle is a "straight truck". Going west, profiles 3B (2%) and 3A (5%) are used. Corresponding reference graphs 13 and 5 in Appendix A give 23 metres for crossing times of 14.0 seconds and 13.5 seconds, respectively. Since the road profile is a mix of two design profiles (3B and 3A), we must decide to use the most conservative time and no interpolation is necessary. The departure time going west is thus 14.0 seconds.

The same process is followed to calculate the departure time when heading east. Profiles 2B (2%) and 2A (5%) are then used. Reference graphs 4 and 3 give 23 metres for crossing times of 15.0 seconds and 16.0 seconds. Here also it is not necessary to interpolate for the corresponding time. Instead, the most conservative time is used for the same reasons as above when heading west. The departure time going east will thus be 16.0 seconds.

4.4.2 Calculating the sight triangle when approaching

The sight triangle when approaching is calculated for both crossing examples. The first is a passive crossing with no mandatory stop signs, so it must be analysed. The second must also be analysed because it is an active crossing that requires additional calculations for the warning time and gate descent time that are presented in the next two sections. Since ABS braking systems are not yet fully integrated into all the heavy vehicles that use our roads, only the data in Table 27 in section 4.3 will be used.

For the example of the passive crossing, the stopping sight distance going north is obtained from Table 27. For 90 km/h and based on the approach gradients of 2% and 5%, the distances of 271 metres and 244 metres are obtained. These results must be interpolated as follows for a gradient of 3%:

$$\frac{x - 244}{271 - 244} = \frac{3\% - 2\%}{5\% - 2\%}$$

$$x = 253 \text{ metres}$$

The stopping sight distance (SSD) for the first crossing heading north is thus 253 metres. The crossing time based on the stopping sight distance (T_{SSD}) is then calculated as follows:

$$T_{SSD}\ (\text{sec}) = \left[\text{SSD} + \text{Clearance distance} + \text{Vehicle length (m)}\right] / \frac{\left[\text{SPEED LIMIT (km/h) - 10 km/h}\right]}{3.6\ \text{s x km/h x m}}$$

$$T_{SSD}\ (\text{north}) = (253 + 19 + 25) / (90 - 10)/3.6 = 13.4\ \text{seconds}$$

Still for the example of the passive crossing, the stopping sight distance going south obtained from Table 27 for 90 km/h and based on a level approach is 294 metres. The stopping sight distance (SSD) heading south is thus 294 metres. The crossing time based on the stopping sight distance (T_{SSD}) is thus:

$$T_{SSD}\ (\text{south}) = (294 + 17.5 + 25) / (90 - 10)/3.6 = 15.1\ \text{seconds}$$

The D_{SSD} (defined in RDT10 as the minimum distance along the rail line that a driver must see an approaching train from the safe stopping distance) is then obtained in each direction by multiplying T_{SSD}(north) and T_{SSD}(south) by the maximum speed of the trains using the tracks. The stopping sight triangles when approaching the first crossing are thus clearly identified.

For the example of the active crossing, the stopping sight distance going west obtained from Table 27 for 50 km/h and based on approach gradients that are level and 2% are 119 and 129 metres. These values must be interpolated for a gradient of 1% as follows:

$$\frac{x - 119}{129 - 119} = \frac{2\% - 1\%}{2\% - 0\%}$$

$$x = 124\ \text{metres}$$

The stopping sight distance (SSD) for the second crossing heading west is thus 124 metres. The crossing time based on the stopping sight distance (T_{SSD}) is then calculated as follows:

$$T_{SSD}\ (\text{west}) = (124 + 23 + 12.5) / (50 - 10)/3.6 = 14.4\ \text{seconds}$$

The stopping sight distance heading east obtained from Table 27 for 50 km/h and based on an approach surface with a downhill gradient of 2% and 5% is 129 metres and 149 metres, respectively. These values must be interpolated for a gradient of 4.5%, as follows:

$$\frac{149 - x}{149 - 129} = \frac{5\% - 4.5\%}{5\% - 2\%}$$

$$x = 145.7\ \text{metres}$$

The stopping sight distance (SSD) heading east will thus be 145.7 metres. The crossing time based on the stopping sight distance (T_{SSD}) is thus:

$$T_{SSD}\ (\text{east}) = (145.7 + 23 + 12.5) / (50 - 10)/3.6 = 16.3\ \text{seconds}$$

The D_{SSD} is then obtained in each direction by multiplying T_{SSD}(west) and T_{SSD}(east) by the maximum speed of the trains using the two tracks. The stopping sight triangles when approaching the second crossing are also thus clearly identified.

4.4.3 Calculating the warning time for active crossings

Note that the warning time for active crossings with flashing lights, gates and audible warnings must be, according to the recommendation in RTD 10, the greater of the following values: 20 seconds, the departure time from a stop in both directions on the road (obtained from the reference graphs), or the crossing time based on the stopping sight distance (obtained from the tables of stopping sight distances).

For the second example of the active crossing, the warning time will thus be 20 seconds, since this value is greater than the respective departure times of 14.0 seconds and 16.0 seconds in both directions on the road that were calculated in section 4.4.1, and it is greater than the crossing times based on a SSD of 14.4 seconds and 16.3 seconds calculated in section 4.4.2.

4.4.4 Calculating the gate arm delay

Section 4.9 of Draft RTD 10 sets out the method to use for determining the gate arm delay according to two distinct scenarios: a stopped position and from the stopping sight distance SSD. In the first instance, the departure time from the reference graph corresponding to a position of 2 metres (the vehicle has crossed its own length plus 2 metres) should be used, and in the second instance, 2 metres and the vehicle length must be added to the SSD. The crossing time for a vehicle over this distance and the legal speed limit less 10 km/h then constitute the reference time.

For the second example of the active crossing, the first method gives times of 9.0 seconds when heading west according to reference graph 13, and 10.0 seconds when heading east according to reference graph 7. With respect to the second method, we then obtain:

$$T(\text{west}) = (124 + 12.5 + 2) / (50 - 10)/3.6 = 12.5 \text{ seconds}$$

$$T(\text{east}) = (145.7 + 12.5 + 2) / (50 - 10)/3.6 = 14.4 \text{ seconds}$$

The longest times obtained in each direction are then used as the reference.

5. CONCLUSIONS AND RECOMMENDATIONS

By using conservative hypotheses, the mathematical acceleration model and the results from the acceleration and braking tests have made it possible to develop a grade crossing design and assessment tool that ensures the safety of the heavy vehicles that use them. The first part of the tool consists of reference graphs of departure times that depend on the road profile, design vehicle chosen, crossing clearance distance and road condition or prohibition from changing gears. Methods for using the reference graphs are also proposed for tanker trucks, for grade crossings near a road intersection, and for grade crossings with poor surface conditions. The second part of the tool is in the form of tables that give the stopping sight distances for vehicles with and without ABS brakes, according to the road profile and the legal speed limit. These tools make it possible to determine sight triangles for grade crossings that are adapted for commercial vehicles of all weights and sizes, for all operating criteria, road conditions, and truck and train speeds, and in normal weather conditions. In addition, the results make it possible to calculate the warning time and gate descent time for active crossings. The adapted tool thus integrates very well into RTD 10 currently being proposed.

Moreover, subsequent to our work, the four recommendations below must be specified:

1. **Integrate the tool into RTD 10, which will make it possible to take the results of this study into account and to determine any anomalies or lack of clarity in the calculations that we have included.**

2. **Standardize the units of measure used in RTD 10 as much as possible to avoid any confusion in the design and assessment calculations.**

3. **The fixed reference crossing times mentioned in RTD 10 should be completely removed.**

The results show that the crossing time used to date for designing grade crossings is generally not justified because it is often too short. For example, the warning time of 20 seconds currently used at active crossings to activate the lights or gates is not always sufficient. Similarly, the stopping sight distance measured along the railway tracks is based on a minimum crossing time of 10 seconds, which is often insufficient for multi-track grade crossings and for long and heavy vehicles. In fact, using fixed times is not at all recommended. Instead, users should be strongly encouraged to systematically use the figures in the reference graphs and tables in the tool for each situation or site.

4. **Various regulations prohibiting drivers of heavy vehicles from changing gears when crossing railway tracks should be abolished.**

Prohibiting drivers from changing gears when crossing railway tracks, as prescribed by several provincial jurisdictions, increases the crossing time for vehicles. Although this practice was justified in the past by the unreliability of transmissions and axles and the possibility of crossing railway tracks more quickly without changing gears, this is no longer the case for current vehicles and so this practice should be re-examined.

BIBLIOGRAPHY

Studies, articles, research reports and others

1. CAIRD, J.K., CREASER, J.I., EDWARDS, C.J., DEWAR, R.E. *A Human Factors Analysis of Highway-Railway Grade Crossing Accidents in Canada* TP 13938E. 112 p. Cognitive Ergonomics Research Laboratory, Department of Psychology, University of Calgary: September 2002.

2. COGHLAN, Mike. *Grade Crossing Safety Issues Raised By: TDG's Bus Acceleration Study and Truck Acceleration Study.* Memorandum. Government of Canada: 3 June 1997.

3. HARWOOD, Douglas W., GLAUZ, William D., MASON, John M. Jr. *Stopping Sight Distance Design for Large Trucks*. Transportation Research Record 1208, pp. 36-45.

4. HARWOOD, Douglas W., GLAUZ, William D., MASON, John M. Jr. et al. *Truck Characteristics for Use in Highway Design and Operation*. Federal Highway Administration Research report, 1990.

5. JONES, Allen. *Impact des véhicules lourds sur la sécurité aux passages à niveau*. Project specifications – File R 452. 5 p. Rail Transport Service – Quebec Department of Transport: 28 November 2001.

6. KENDALL, Kenneth, MORRISSETTE, Lise. *Truck Acceleration Study.* Final report, TP 12490E. Transport of Dangerous Goods Directorate, Transport Canada: May 1995.

7. KNAPP, Keith K. *Literature Review of Highway-Railroad Grade Crossing Sight Distance Assumptions*. ITE Journal, November 1999, pp. 32-37.

8. LEBEL, Luc, TREMBLAY, Pierre-Serge. *Les routes forestières : lien vital entre la ressource et les usines.* Routes et transports, Winter 2002, Volume 31, Number 1, pp. 21-24.

9. MICHAELSEN, Jan. *Le camionnage hors normes en forêt.* Routes et transports, Winter 2002, Volume 31, Number 1, pp. 32-37.

10. PELLETIER, Lyse. *La gestion de la sécurité routière pour le transport forestier : un capital à investir et à préserver.* Routes et transports, Winter 2002, Volume 31, Number 1, pp. 25-31.

11. PETERS, George A., PETERS, Barbara J. *The Distracted Driver - How Dangerous is "Multitasking"?* Professional Safety, March 2002, pp. 34-36.

12. READ, John A. *Safety at Passively Protected Rail-Highway Crossings.* Report presented at the "Conference on Truck Safety: Perceptions and Reality", Toronto, 11 to 13 September, 1995.

13. TARDIF, L-P, & ASSOCIATE INC., *Grade Crossing Contraventions and Motor Carrier Safety Assessment,* Technical report presented to Transport Canada, Transportation Development Centre: March 2001 TP 13792E.

14. TRANSPORTATION DEVELOPMENT CENTRE, RAIL SAFETY DIRECTORATE. Workshop on Rail-Highway Grade Crossing Research, Ottawa, 18 November 1999. *Proceedings of the Workshop on Rail-Highway Grade Crossing Research*. Transport Canada, Montreal, March 2000. 161 p.

15. TRANSPORTATION DEVELOPMENT CENTRE, RAIL SAFETY DIRECTORATE. Second Workshop on Rail-Highway Grade Crossing Research, Montreal, 15 November 2000. *Proceedings of the Second Workshop on Rail-Highway Grade Crossing Research*. Transport Canada, Montreal, February 2001, 235 p.

Acts, standards and regulations

16. *Geometric Design Guide for Canadian Roads*. Transportation Association of Canada, September 1999.

17. *Vehicle Load and Size Limits Guide*. Quebec Department of Transport, 2000 Edition, pp. 8-18.

18. *Draft RTD 10 - Road/Railway Grade Crossings: Technical Standards and Inspection, Testing and Maintenance Requirements*. Rail Safety Directorate, Safety and Security, Transport Canada, 14 June 2002 and preceding versions.

19. *Grade Crossing Regulations*. 10000-32 (GC-1/GC-1). Regulation proposed by the Governor in Council in compliance with the Railway Safety Act, 13 June 2002.

20. *Railway-Highway Crossing at Grade Regulations*. General Order from the Canadian Transportation Agency No. E-4. Railway Act, National Transportation Act, Transport Canada.

Regulations governing mandatory stops and prohibiting the changing of gears

21. *British Columbia Motor Vehicle Act,* R.S.B.C. 1996, c. 318.

22. *Alberta Highway Traffic Act,* R.S.A. 1980, c. H-7.

23. *The School Bus Operating Regulations*, Saskatchewan 1987, c. H-3.1 Reg. 5.

24. *Saskatchewan Highway Traffic Act*, S.S. 1986, c. H-3.1.

25. *Manitoba Highway Traffic Act*, S.M. 1986, c.3 c. H-60

26. *Ontario Highway Traffic Act*, R.S.O. 1990, c. H-8

27. *Quebec Highway Safety Code*, R.S.Q. 1999, c. C-24.2

28. *New Brunswick Motor Vehicle Act*, R.S.N.B. 1986, c. M-17

29. *Newfoundland and Labrador Highway Traffic Act*, R.S.N.L. 1990, c. H-3

30. *Yukon Motor Vehicles Act*, R.S.Y. 1986, c. 11

31. *Northwest Territories Motor Vehicles Act*, R.S.N.W.T. 1988, c. 106

Transportation Safety Board Occurrence Reports

32. *Report R94C0035*. Occurrence Report, Transportation Safety Board, publication authorized on 21 September 1995.

33. *Report R94D0191*. Occurrence Report, Transportation Safety Board, publication authorized on 16 December 1997.

34. *Report R94M0100*. Occurrence Report, Transportation Safety Board, publication authorized on 13 December 1996.

35. *Report R94V0206*. Occurrence Report, Transportation Safety Board, publication authorized on 30 April 1996.

36. *Report R95D0081*. Occurrence Report, Transportation Safety Board, publication authorized on 12 December 1996.

37. *Report R99H0009*. Occurrence Report, Transportation Safety Board, publication authorized on 16 January 2002.

38. *Report R99T0298*. Occurrence Report, Transportation Safety Board, publication authorized on 11 September 2001.

39. *Report R00C0159*. Occurrence Report, Transportation Safety Board, publication authorized on 4 February 2002.

Internet sites

40. Direction 2006 - http://www.direction2006.com/sample/intro.htm

41. FHWA - Grade Crossing Handbook - http://www.fhwa.dot.gov/tfhrc/safety/pubs/86215/86215.pdf

42. FRA - http://www.fra.dot.gov

43. Quebec Department of Transport - http://www.mtq.gouv.qc.ca/index.asp

44. Operation Lifesaver - http://www.ol-og-canada.org/ (home page)
    http://www.ol-og-canada.org/docs/francais/princ/home2.html (French page)

45. Transport Canada - http://www.tc.gc.ca/en/menu.htm

46. Société de l'assurance automobile du Québec - http://www.saaq.gouv.qc.ca/

47. Transportation Safety Board – Occurrence Reports - http://www.tsb.gc.ca/en/index.asp

48. US Department of Transportation, 2001 Green Book -
    http://www.fhwa.dot.gov/programadmin/y2kgb3.htm

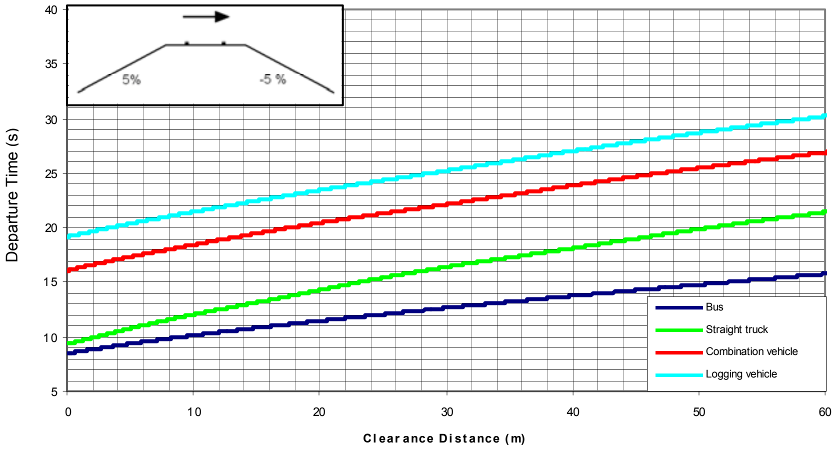
49. Volpe National Transportation System Center - http://www.volpe.dot.gov/

APPENDIX A

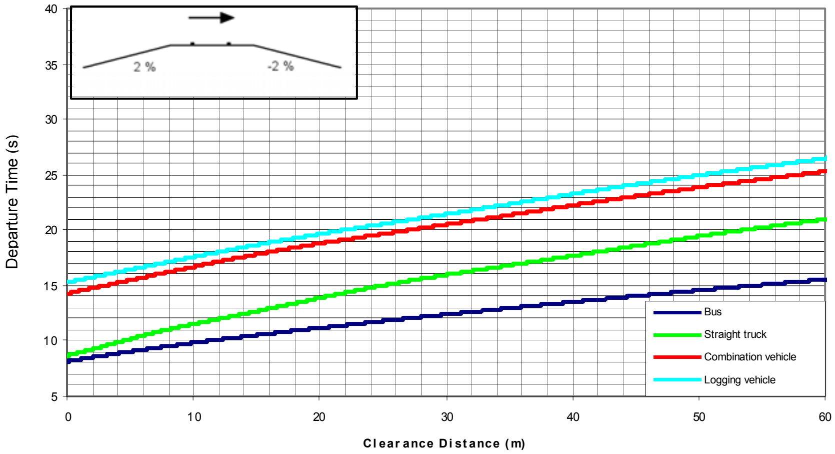
Reference Graphs for Departure Times

Reference graphs #1-17

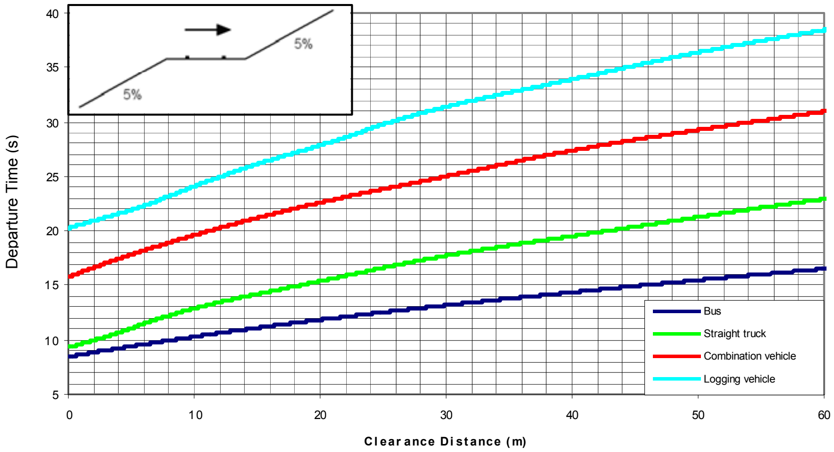
Graph 1 - Departure Time According to Clearance Distance for Profile 1-A



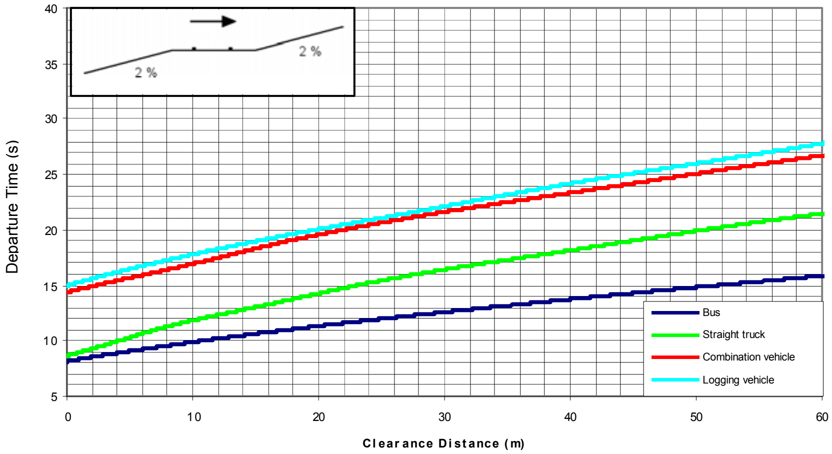
Graph 2 - Departure Time According to Clearance Distance for Profile 1-B



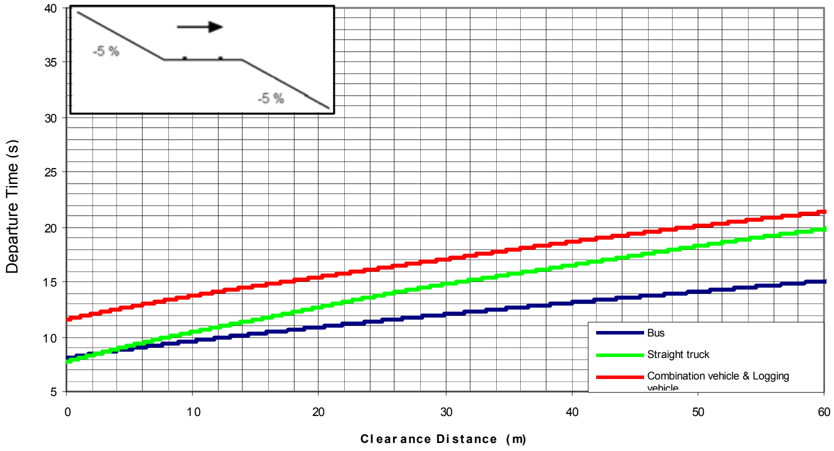
Graph 3 - Departure Time According to Clearance Distance for Profile 2-A



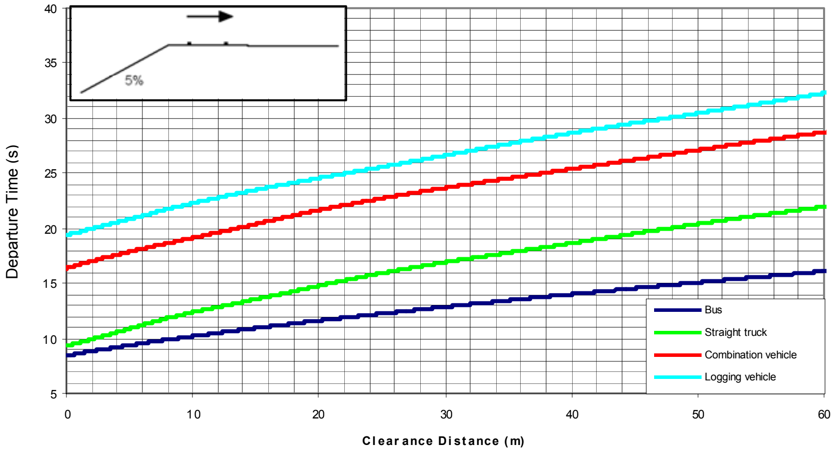
Graph 4 - Departure Time According to Clearance Distance for Profile 2-B



Graph 5 - Departure Time According to Clearance Distance for Profile 3-A



Graph 6 - Departure Time According to Clearance Distance for Profile 4-A



Graph 7 - Departure Time According to Clearance Distance for Profile 4-B

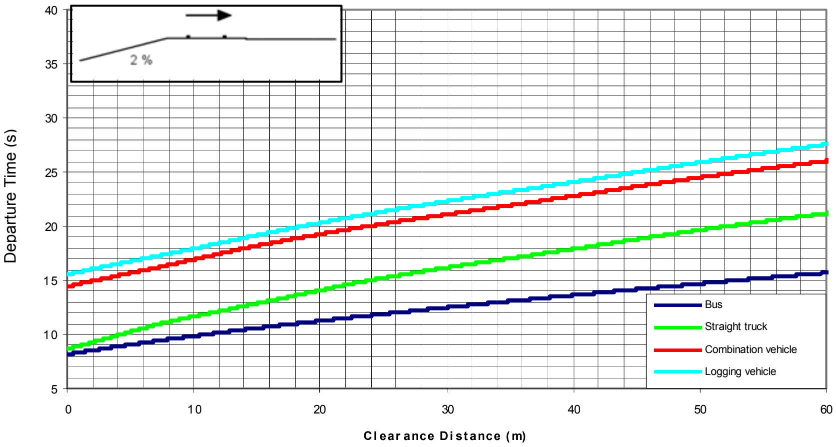
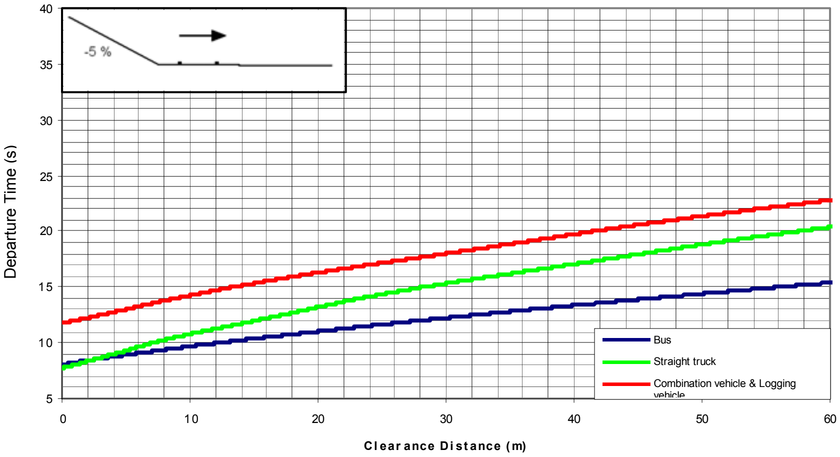
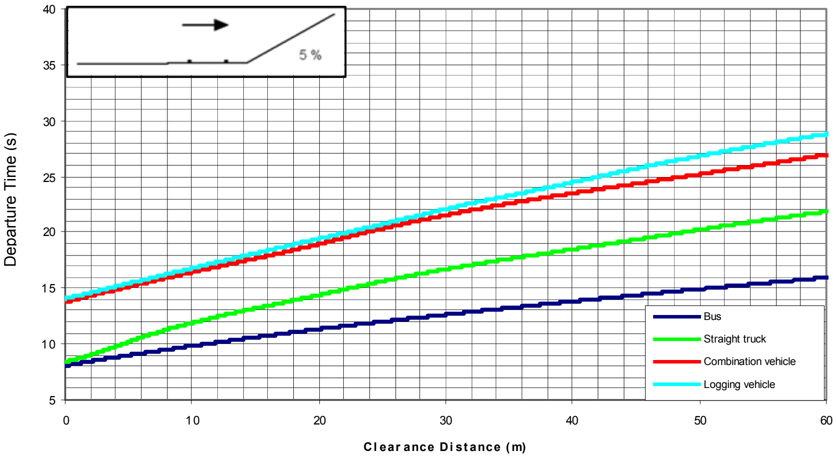


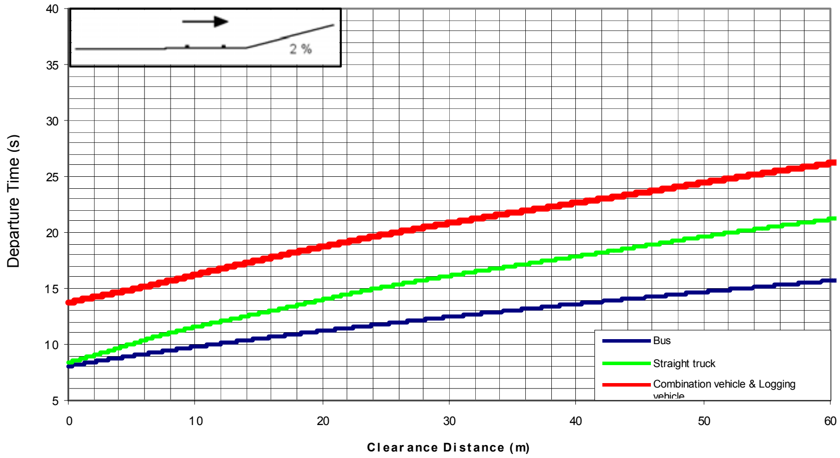
Chart 8 - Departure Time According to Clearance Distance for Profile 6-A



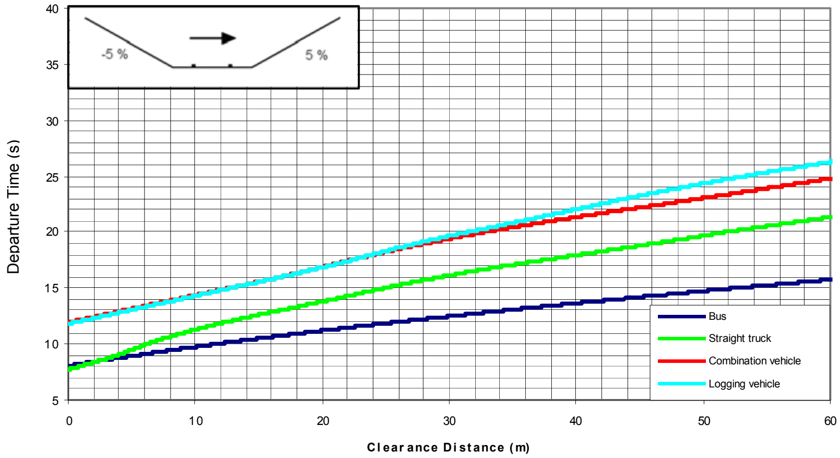
Graph 9 - Departure Time According to Clearance Distance for Profile 7-A



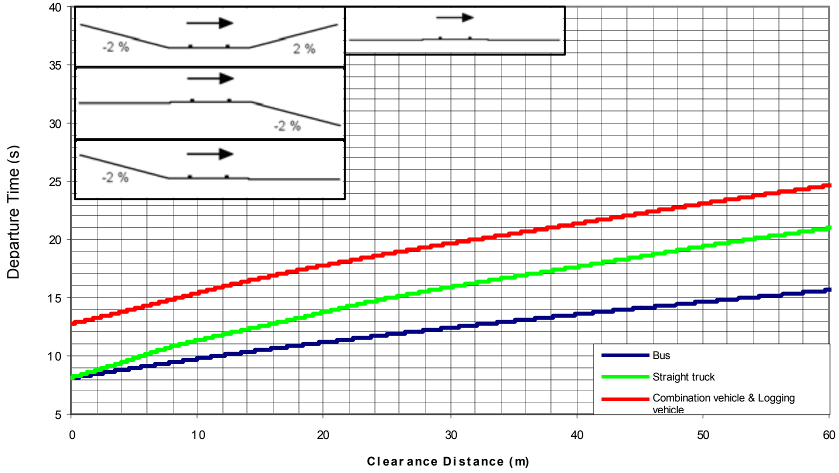
Graph 10 - Departure Time According to Clearance Distance for Profile 7-B



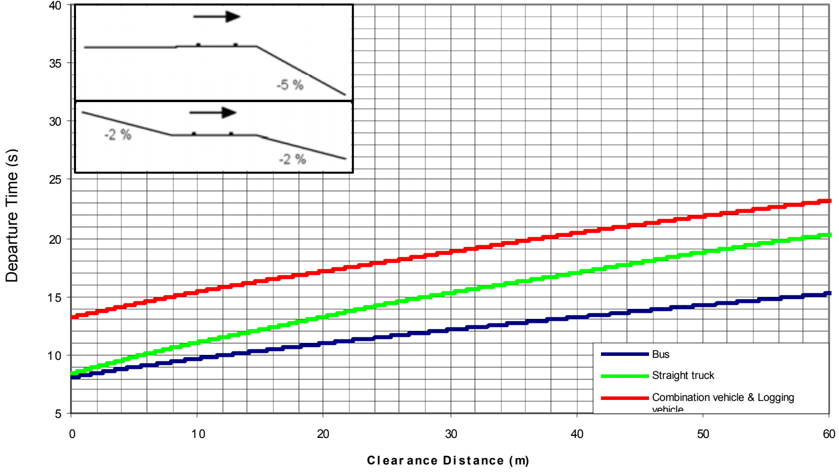
Graph 11 - Departure Time According to Clearance Distance for Profile 8-A



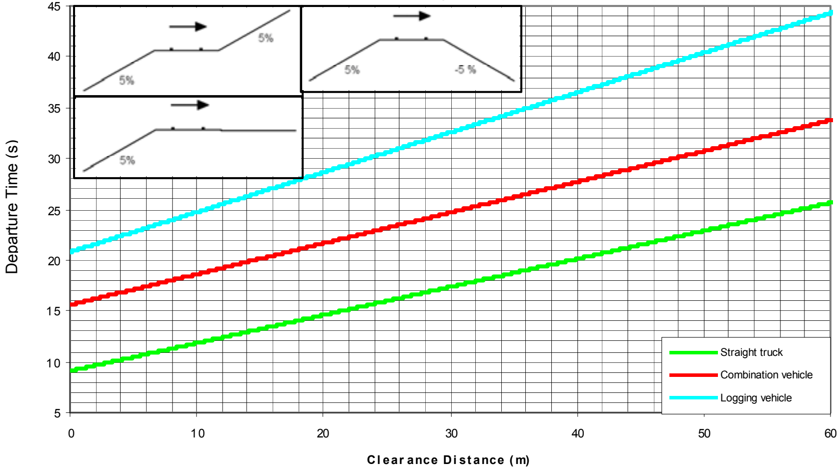
Graph 12 - Departure Time According to Clearance Distance for a Level Profile, and Profiles 5-B, 6-B and 8-B



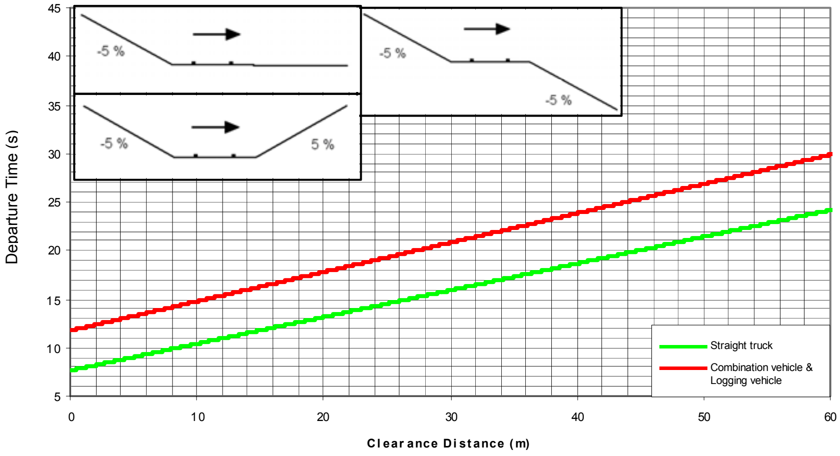
Graph 13 - Departure Time According to Clearance Distance for Profiles 3-B and 5-A



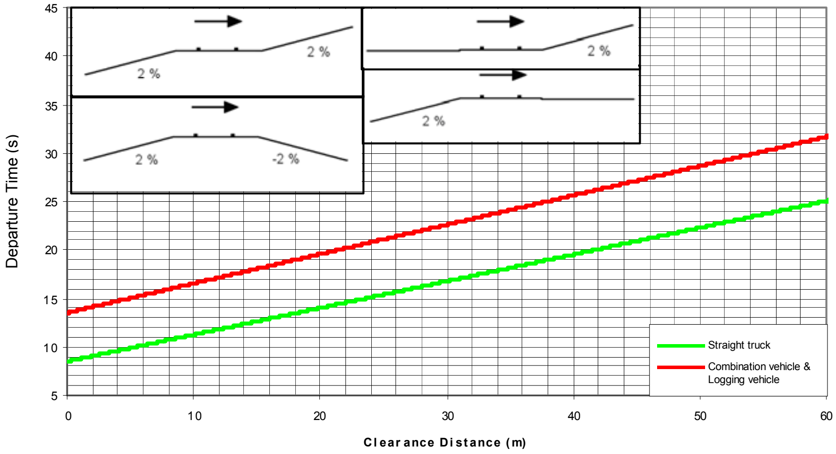
Graph 14 - Departure Time According to Clearance Distance for Profiles 1-A, 2-A and 4-A Without a Change in Transmission Ratio



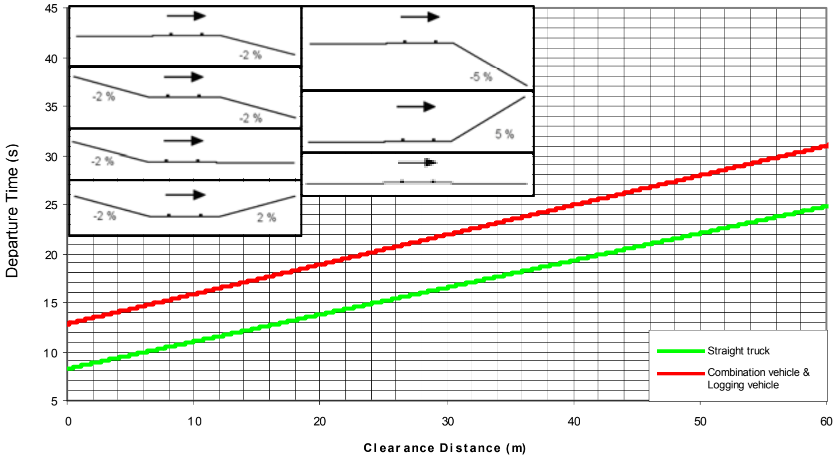
Graph 15 - Departure Time According to Clearance Distance for Profiles 3-A, 6-A and 8-A Without a Change in Transmission Ratio



Graph 16 - Departure Time According to Clearance Distance for Profiles 1-B, 2-B, 4-B and 7-B Without a Change in Transmission Ratio



Graph 17 - Departure Time According to Clearance Distance for a Level Profile, and Profiles 3-B, 5A, 5-B, 6-B, 7A and 8-B Without a Change in Transmission Ratio



APPENDIX B

Special Project

Grade Crossings Used by Heavy Vehicles with Dropped Chassis Frames

Project objectives:

- From a geometric aspect, study the impact of semi-trailers with dropped chassis frames (LOW-BOY trailers) at grade crossings
- According to current standards in effect
- According to draft RTD 10 standard

Methodology:

- 2D modelling of a grade crossing and a tractor semi-trailer combination on AutoCAD
- Use of the most critical crossing profiles permitted for each of the regulations (current and RTD 10)
- Critical position of the tractor semi-trailer when the centre of the trailer wheel space passes over the highest part of the crossing
- Identification of the clearance or interface between the semi-trailer and the surface

Hypotheses retained:

- Semi-trailer loaded to full capacity
- Rigid suspensions (constant distance between the ground and the king pin, and between the median axle of the semi-trailer and its chassis)
- Articulation in the vertical plane only at the fifth wheel

Semi-trailer modelled:

- Talbert low bed trailer, model 55SA
- Minimum clearance of 6 inches on a level surface
- Typical longest and lowest vehicle chassis currently available on the North American market

TALBERT Low Bed Trailer 55SA

Critical scenario with current standards:

- Uphill and downhill grades of 5%
- Railway tracks not canted

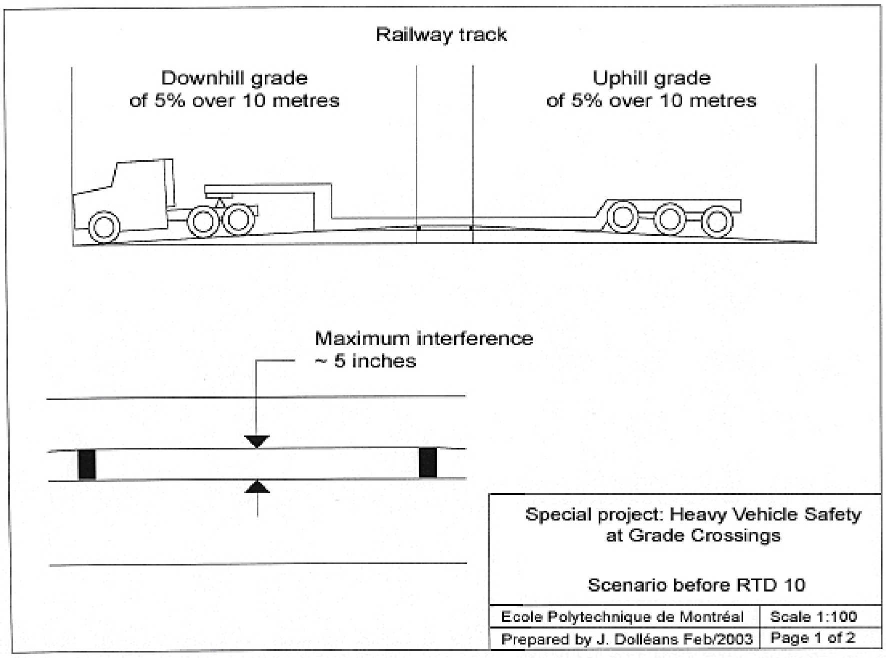


Diagram of the interference between the low chassis and the rails based on the critical scenario with current standards

There is a potential for vertical interference of about 5 inches (12.7 cm) between the chassis and the rails. This explains why incidents sometimes occur with this type of vehicle at some higher-risk grade crossings.

Critical scenario with draft RTD 10:

- Grades of 2% in a radius of 8 metres from the closest rail and 5% over the next 10 metres
- Railway tracks canted by 1%
- Rails elevated by 1 inch to simulate a poor crossing surface

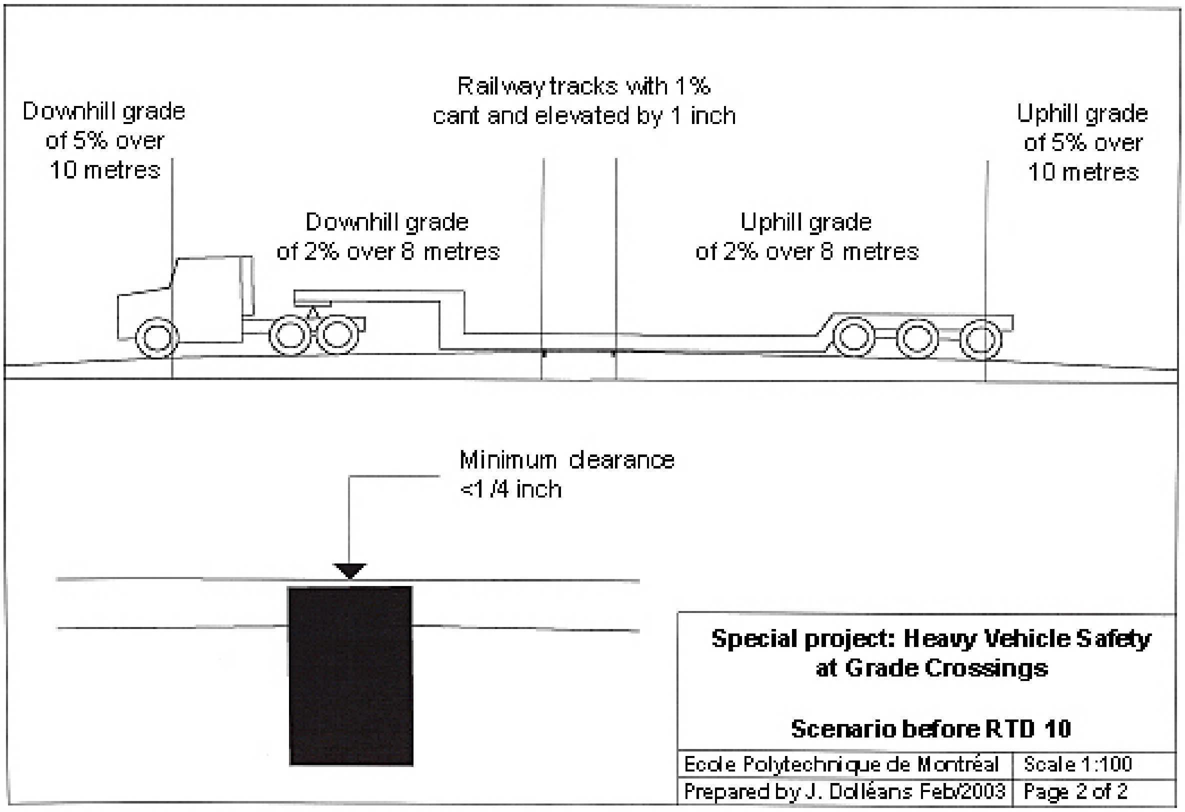


Diagram of the interference between the low chassis and the rails based on the critical scenario with draft RTD 10

There is also a potential for vertical clearance of less than ¼ inch (0.63 cm) between the chassis and the rails, which is probably insufficient.

Conclusions:

- The current standards are clearly inadequate for situations in which vehicles with dropped chassis frames must use a crossing that presents a risk. There is a potential for vertical interference between the chassis and the rails, which can cause the vehicle to get stuck on the rails, or which can damage the vehicle and the rails.
- The critical scenario with the draft RTD 10 standard provides minimal vertical clearance. However, there is still a possibility of interference in specific situations. For instance, when bad road conditions are combined with the poor mechanical condition of a vehicle's suspension (sagging) or wheels (poorly inflated).
- Draft RTD 10 makes it possible to greatly improve the problems encountered by vehicles with dropped chassis frames when using grade crossings.
- The maintenance of the rails and the road, and the good mechanical condition of vehicles are also necessary criteria to ensure a safe crossing for these types of vehicles, even with the amendments made with the development of draft RTD 10.

APPENDIX C

Provincial Regulations Governing Mandatory Stops and Prohibiting the Changing of Gears when Crossing Railway Tracks

British Columbia

Motor Vehicle Act, R.S.B.C. 1996, c. 318

Railway crossings

185 (1) When a driver is approaching a railway crossing at a time when

(a) a clearly visible electrical or mechanical signal device gives warning of the approach of a railway train,
(b) a crossing gate is lowered or a flagger is giving a signal of the approach or passage of a railway train, or
(c) a railway train is approaching and is within approximately 500 m of a crossing or by reason of its speed or nearness to the crossing is an immediate hazard and emits an audible signal or is visible, the driver must stop the vehicle within 15 m but not less than 5 m from the nearest rail of the railway, and must not cause or permit the vehicle to proceed until he or she can do so safely.

(2) A person must not drive a vehicle through, around or under a crossing gate or barrier at a railway crossing while the gate or barrier is closed or is being opened or closed.

(3) If a stop sign is erected at a railway crossing, a driver approaching the railway crossing

(a) must stop his or her vehicle
  (i) no closer than 5 m, and
  (ii) no farther than 15 m from the nearest rail of the railway, and
(b) must not proceed until he or she can do so safely.

(4) Except at a railway spur line or an industrial track in a business or residence district, the driver of

(a) a bus carrying passengers for compensation,
(b) a school bus carrying a child,
(c) a vehicle carrying explosive substances or any poisonous or flammable substance as cargo, or
(d) a vehicle used to carry flammable liquids or gas, whether or not it is then empty, approaching a railway crossing that is not protected by gates or railway crossing signal lights, unless otherwise directed by a flagger, must
(e) stop his or her vehicle
  (i) no closer than 5 m, and
  (ii) no farther than 15 m from the nearest rail of the railway,
(f) remaining stopped, must listen and look in both directions along the railway for an approaching train, and for signals indicating the approach of a train, and
(g) must not proceed until he or she can do so safely.

(5) When a driver has stopped in accordance with this section, the driver must
(a) cross the railway tracks in a gear that he or she will not need to change while crossing the tracks,
(b) not shift gears while so crossing, and
(c) not stop with a part of the vehicle on or over the tracks.

(6) Despite this Act, the driver of a vehicle approaching the track of a railway must proceed with caution to avoid a collision between the vehicle and an approaching train.

Alberta

Highway Traffic Act, R.S.A. 1980, c. H-7

104 – Railway Crossing

(1) At a railway crossing at any time when

- (a) a clearly visible electrical or mechanical signal device gives warning of the approach of a railway train,
- (b) a crossing gate is lowered or a flagperson is giving a signal of the approach or passage of a railway train,
- (c) a railway train within approximately 500 metres of the crossing is approaching the crossing and either sounds an audible signal or is visible, or
- (d) a railway train is visible and approaching the crossing and by reason of its speed or nearness is an immediate hazard, a driver of a vehicle approaching the railway crossing
- (e) shall stop that vehicle no closer than 5 metres from the nearest rail of the railway, and
- (f) shall not proceed until the train
  - (i) has passed by the railway crossing, or
  - (ii) has come to a stop,

  and the driver can safely proceed.

(2) No person shall drive through, around or under a crossing gate or barrier at a railway crossing while the gate or barrier is closed or is being opened or closed.

(3) If a stop sign is erected at a railway crossing, a driver of a vehicle approaching the railway crossing

- (a) shall stop that vehicle
  - (i) no closer than 5 metres, and
  - (ii) no further than 15 metres,

  from the nearest rail of the railway, and
- (b) shall not proceed until the driver can do so safely.

(4) In the case of a railway crossing that is not controlled by a traffic control signal, the driver of a vehicle that

- (a) is a school bus,
- (b) is carrying explosive substances as cargo, or
- (c) is used for carrying inflammable liquids or gas, whether or not it is then empty,

shall stop that vehicle no closer than 5 metres or further than 15 metres from the nearest rail of the railway, and

- (d) remaining stopped, shall listen and look in both directions along the railway for an approaching train and for signals indicating the approach of a train,
- (e) shall not proceed until the driver can do so safely, and

(f) in the case of a school bus, shall before proceeding open the front door and if practicable to do so with one hand, shall also open the window immediately to that driver's left.

(5) Subsection (4) does not apply when a peace officer or a flagperson otherwise directs.

(6) The council of a city may, by bylaw, provide that subsection (4) does not apply to all or any railway crossings in the city.

(7) When a driver of a vehicle has stopped that vehicle in accordance with this section, the driver

(a) shall cross the railway tracks with the vehicle in a gear that the driver will not need to change while crossing the tracks, and
(b) shall not shift gears while so crossing.

Saskatchewan

The School Bus Operating Regulations, 1987, c. H-3.1 Reg. 5

4. Every driver shall:

  (e) when approaching an uncontrolled railroad crossing:
    (i) move the bus as far to the right as is practical;
    (ii) activate the hazard warning lamps:
      (A) on a highway with a speed limit of more than 50 kilometres per hour, not less than 100 metres from a railroad crossing; and
      (B) on a highway with a speed limit of 50 kilometres per hour or less, not less than 25 metres from the railroad crossing;
    (iii) stop the bus not less than four and not more than 10 metres from the railroad crossing;
    (iv) open the front door of the bus and look in both directions;
    (v) proceed across the tracks when it is safe to do so and, in the case of standard transmissions, remain in first gear until the bus is completely clear of the tracks; and
    (vi) move back into the travelled portion of the highway when it is safe to do so and deactivate the hazard warning lamps;

Highway Traffic Act, S.S. 1986, c. H-3.1

40. Stopping

(5) The driver of :

(a) a bus transporting passengers; or
(b) a vehicle that is transporting goods in an amount that requires the vehicle to be placarded pursuant to regulations made pursuant to *The Dangerous Goods Transportation Act*;
(c) Repealed. 1989-90, c.10, s.9.

shall bring the vehicle to a stop before proceeding over a level railway crossing.

(6) No person who is required to stop pursuant to subsection (4) or (5) shall proceed until it is safe to do so.

(7) Subsection (5) does not apply if an automatic signal is erected at the railway crossing and the signal indicates that it is safe to proceed.

Manitoba

Highway Traffic Act, S.M. 1986, c. 3 c. H-60

135 (1) Stops by certain vehicles at railways

Except as provided in subsections (3) and (4), the driver of

(a) a vehicle carrying passengers for compensation; or
(b) a school bus carrying children; or
(c) a vehicle carrying flammable liquids or gas, whether or not it is then empty;

approaching a railway crossing shall stop the vehicle not less than 5 metres, or more than 15 metres, from the nearest rail of the railway, and, with the vehicle stopped, shall :

(d) look in both directions along the railway for an approaching train;
(e) listen for signals indicating the approach of a train; and
(f) in the case of a bus or school bus, open the door of the vehicle; and he shall not proceed unless he can do so in safety.

135 (2) Crossing railway without changing gear

Except as provided in subsection (4), where a driver has stopped and is proceeding as required in subsection (1), he shall cross the railway track in a gear that he will not need to change while crossing the track, and he shall not shift gears while crossing.

135 (3) Where subsection (1) does not apply

Subsection (1) does not apply where :

(a) a peace officer or a flagman directs traffic to proceed; or
(b) the crossing is protected by gates or a railway crossing signal light which are not in operation at the time.

135 (4) Where subsections (1) and (2) not applicable

Subsections (1) and (2) do not apply to

(a) street railway grade crossing within a restricted speed area; or
(b) industrial spur railway crossings within a restricted speed area.

Ontario

Highway Traffic Act, R.S.O. 1990, c. H-8

Public vehicles required to stop

174 (1) The driver of a public vehicle upon approaching on a highway a railway crossing that is not protected by gates or railway crossing signal lights, unless otherwise directed by a flagman, shall :

(a) stop the vehicle not less than 5 metres from the nearest rail of the railway;
(b) look in both directions along the railway track;
(c) open a door of the vehicle and listen to determine if any train is approaching;
(d) when it is safe to do so, cross the railway track in a gear that will not need to be changed while crossing the track; and
(e) not change gears while crossing the railway track.

(2) School buses required to stop

The driver of a school bus, within the meaning of section 175, upon approaching on a highway a railway crossing, whether or not it is protected by gates or railway crossing signal lights, unless otherwise directed by a flagman, shall :

(a) stop the school bus not less than 5 metres from the nearest rail of the railway;
(b) look in both directions along the railway track;
(c) open a door of the school bus and listen to determine if any train is approaching;
(d) when it is safe to do so, cross the railway track in a gear that will not need to be changed while crossing the track; and
(e) not change gears while crossing the railway track. 1997, c. 12, s. 13.

Quebec

Highway Safety Code, R.S.Q. 2003, c. C-24.2

Level crossing.

411. At a level crossing, the driver of a road vehicle or any person riding a bicycle must stop his vehicle not less than 5 metres from the railway where a sign or signal, a lowered gate or a railway employee signals an approaching rail vehicle, or where the driver or cyclist sees or hears a rail vehicle approaching the level crossing.
1986, c. 91, s. 411

Insufficient space.

412. Even if so authorized by traffic lights, no driver of a road vehicle may enter a level crossing if there is not sufficient space ahead of the vehicle to allow him to cross the level crossing.
1986, c. 91, s. 412.

Level crossing.

413. The driver of a bus, minibus or road vehicle carrying certain categories of dangerous substances determined by regulation must stop his vehicle not less than 5 metres from any level crossing. The driver may then proceed only after ascertaining that he may do so in safety.

Exemption.

The driver is exempt from the obligations under the first paragraph at level crossings where so indicated by a sign or signal.
1986, c. 91, s. 413.

Exemption.

414. The Minister of Transport may, by an order published in the *Gazette officielle du Québec*, designate certain level crossings where the driver of a road vehicle referred to in section 413 is exempt from the obligations under the said section.
1986, c. 91, s. 414.

Level crossing.

519.13. A driver of a heavy vehicle must, unless exempted from doing so by regulation or by a sign or signal, stop the heavy vehicle at least five metres from any level crossing and then proceed only after ascertaining that it is safe to proceed.

New Brunswick

Motor Vehicle Act, R.S.N.B. 1986, c. M-17

Railway Crossings

182(1) Any person driving a vehicle approaching a railroad grade crossing shall stop such vehicle within fifteen metres, but not less than five metres from the nearest rail of such railroad, when

(a) a clearly visible electric or mechanical signal device, designed to give warning of the approach of a railroad train, is exhibiting a warning signal,
(b) a crossing gate is lowered or when a human flagman gives or continues to give a signal of the approach of a railroad train,
(c) a railroad train approaching within approximately five hundred metres of the highway crossing emits a signal audible from such distance and such railroad train, by reason of its speed or nearness to such crossing, is an immediate hazard, or
(d) an approaching railroad train is plainly visible and is in hazardous proximity to such crossing and shall not thereafter cross over the railroad track or tracks until the imminent danger from traffic on the railroad has ceased to exist.

182(2) No person shall drive any vehicle through, around, or under any crossing gate or barrier at a railroad crossing while such gate or barrier is closed or is being opened or closed.

183(1) The following may cause stop signs to be erected at railway crossings:

(a) local authorities, within their jurisdictions;
(b) the New Brunswick Highway Corporation, with respect to railway crossings at highways under its administration and control; and
(c) the Minister, with respect to railway crossings at all other highways, including, without limiting the generality of the foregoing, those under the administration and control of a project company.

183(2) No such stop sign shall be erected by a local authority without the approval of the Lieutenant-Governor in Council.

183(3) The driver of a vehicle that is approaching a railway crossing at which a stop sign has been erected shall stop the vehicle within fifteen metres, but not less than five metres, from the nearest rail of the railway and shall not proceed until it is safe to do so.

184(1) The driver of any motor vehicle carrying passengers for hire, or of any bus, or of any vehicle carrying explosive substances or flammable liquids as a cargo or part of a cargo, before crossing at grade any tracks of a railroad, shall stop such vehicle within fifteen metres, but not less than five metres from the nearest rail of such railroad and while so stopped shall listen and look in both directions along such tracks for any approaching train, and for signals indicating the approach of a train, and shall not proceed until he can do so safely.

184(1.1) Subject to subsection 182(1), subsection (1) does not apply to the driver of a motor vehicle carrying passengers for hire, of a bus or of a vehicle carrying explosive substances or flammable liquids as a cargo or part of a cargo, before crossing the tracks of a railroad if the crossing is equipped with a railroad sign that

(a) is installed before the crossing so as to be clearly visible to approaching drivers,
(b) bears a symbol depicting a railroad crossing, and
(c) is equipped with two yellow lights that flash alternately when they are activated upon the approach of a train.

184(2) After stopping as required by subsection (1), and upon proceeding when it is safe to do so, the driver of any such vehicle shall cross with the vehicle so geared that there will be no necessity for changing gears while traversing such crossing and the driver shall not shift gears while crossing the track or tracks.

184(3) No stop need be made at any such crossing where a police officer or a traffic control signal directs traffic to proceed.

Newfoundland and Labrador

Highway Traffic Act, R.S.N.L. 1990, c. H-3

Crossing tracks

134.(1) A driver of

(a) a vehicle carrying passengers for compensation;
(b) a school bus carrying a child; or
(c) a vehicle carrying explosive substances or inflammable liquids as cargo

before crossing a track of a railway, shall stop the vehicle not less than 5 metres from the nearest rail and, remaining stopped, shall listen and look in both directions along the track for an approaching train and for signals indicating the approach of a train and shall not proceed until it is safe to do so.

(2) Where a driver has stopped and is proceeding in accordance with subsection (1), the driver shall cross the railway track in a gear that will not need to be changed while crossing the track and the driver shall not shift gears while crossing.

(3) Subsection (1) does not apply where a traffic officer or traffic-control device directs traffic to proceed.

(4) Subsections (1) and (2) do not apply to industrial spur railway crossings within an urban district.

Yukon

Motor Vehicles Act, R.S.Y. 1986, c. 11

Railway crossings

164.(1) At a railway crossing at any time when

(a) a clearly visible electrical or mechanical signal device gives warning of the approach of a railway train,
(b) a crossing gate is lowered or a flagperson is giving a signal of the approach or passage of a railway train,
(c) a railway train within approximately 500 metres of the crossing is approaching the crossing and either sounds an audible signal or is visible, or
(d) a railway train is visible and approaching the crossing and by reason of its speed or nearness is an immediate hazard,

a driver approaching the railway crossing

(f) shall not proceed until the train has passed by the railway crossing or has come to a stop and he can safely proceed.

(2) No person shall drive through, around or under a crossing gate or barrier at a railway crossing while the gate or barrier is closed or is being opened or closed.

(3) Where a stop sign is erected at a railway crossing, a driver approaching the railway crossing

(a) shall stop his vehicle no closer than five metres and no further than 15 metres from the nearest rail of the railway, and
(b) shall not proceed until he can do so safely.

(4) In the case of a railway crossing that is not controlled by a traffic control signal, the driver of a vehicle that

(a) is a school bus,
(b) is carrying explosive substances as cargo, or
(c) is used for carrying flammable liquids or gas, whether or not it is then empty, shall stop the vehicle no closer than five metres or further than 15 metres from the nearest rail of the railway, and
(d) remaining stopped, shall listen and look in both directions along the railway for an approaching train and for signals indicating the approach of a train,
(e) shall not proceed until he can do so safely, and
(f) in the case of a school bus, shall before proceeding open the front door and where practicable to do so with one hand, shall also open the window immediately to his left.

(5) Subsection (4) does not apply where a peace officer or a flagperson otherwise directs.

(6) A municipality may, by bylaw, provide that subsection (4) does not apply to all or any railway crossings in the city.

(7) Where a driver has stopped in accordance with this section, he

- (a) shall cross the railway tracks in a gear that he will not need to change while crossing the tracks, and
- (b) shall not shift gears while so crossing.

Northwest Territories and Nunavut

Motor Vehicles Act, R.S.N.W.T. 1988, c. 106

213. School bus at railway crossing

A driver of a school bus carrying students shall, on approaching a railway crossing,

a) stop the bus not less than 5 m from the nearest rail of the crossing; and
b) listen and look in both directions of the crossing for an approaching train.

When to proceed

214. A driver who has brought his or her school bus to a stop under section 213 shall

a) not proceed across the railway crossing until it is safe to do so;
b) enter the railway crossing in a gear that will enable the bus to cross the tracks without having to shift gears; and
c) not shift gears while crossing the railway crossing.