Proceedings of the 2014 Global Level Crossing Symposium
4-8 August 2014, Urbana, IL, USA

GLXS2014-1085

MITIGATING RISKY BEHAVIOUR OF DELAYED ROAD USERS AT OCCUPIED HIGHWAY-RAILWAY CROSSINGS: REVIEW OF RESEARCH AND ISSUES

Ian Naish
Naish Transportation Consulting
Ottawa, Ontario, Canada

Daniel Blais
Transport Canada, Transportation Development Centre
Ottawa, Ontario, Canada

ABSTRACT

This paper reviewed Canadian, US and overseas literature records, and other sources, with the primary intent of identifying human factors issues related to road users who are delayed or blocked at railway crossings. Other significant issues examined related to regulatory, operational and technical factors at crossings related to the delay problem, as well as possible solutions to mitigate or eliminate the delay problem. The report covers the two major aspects of crossing blockages: crossings blocked by slow moving or stationary trains; and delays at crossings caused by excessive signal operation. It identifies human behaviour literature in the areas of risk taking, anger, aggression and delay perception, as well as road user (motorists and pedestrians) compliance with crossing warning systems, and technological solutions to mitigate the problem. Sample benefit-cost analyses of some alternatives to reduce road user delay are presented, and include the assumptions made.

INTRODUCTION

Over the last two decades in Canada, there has been a trend towards increased crossing blockages and associated delays to road users. This phenomenon has occurred in parallel with a similar change in the United States. According to the Federal Railroad Administration [1], rail traffic has been increasing for decades while net track miles have been decreasing over that period, concentrating more traffic on fewer lines across the country. Trains have become progressively longer and, as a result, sidings have been extended to accommodate the trains when meeting others on single track main lines. However, the siding extensions have also resulted in the potential for more roadways to be blocked. This negatively affects both cities and smaller communities that lie along rail corridors. At the same time, crossings at or near the throats of rail yards are experiencing severe blockage problems because movements of long trains in and out are typically through low speed turnouts (i.e. a location where trains can be switched from one track to another). Many of these yards are in industrial areas, including ports, and have a major impact on road traffic, both commercial and general public.

Rule 103.(d) of the Canadian Rail Operating Rules[2] states that: *Except at those public crossings indicated in special instruction, no part of a movement may be allowed to stand on any part of a public crossing at grade, for a longer period than five (5) minutes, when vehicular or pedestrian traffic requires passage. Switching operations at such crossing must not obstruct vehicular or pedestrian traffic for a longer period than five (5) minutes at a time. When emergency vehicles require passage, employees must cooperate to quickly clear the involved crossings.*

Rule 103 does not address obstruction of crossings by slow moving trains. Since the operation of long trains over crossings can be at very low speeds, there is a potential for critical emergency response problems as well as road user frustration.

Road users who either anticipate being delayed for long periods of time at blocked railway crossings, or who are actually delayed, may engage in high-risk behaviour such as: trying to ‘beat the train’; driving around gates; performing illegal u-turns or back-up movements. Delayed pedestrians may climb through stopped or slow-moving cars rather than wait for the track to clear. These risky behaviours endanger the road users and can lead to incidents that result in serious injuries or fatalities. In addition, it has a significant negative effect on railway operations, if an accident occurs.

Unfortunately, there is very little literature on human factors issues regarding risk taking behaviour by road users delayed at crossings, or on countermeasures that could be implemented to discourage risk taking behaviour in that situation. However, as referenced later in this paper, there is behavioural information for road users delayed at crossings by excessive operation of signals, or where crossing gates remain down over extended periods.

While this paper has a primary focus on human factors issues, other issues are reviewed as well, including: proximity/land use; different types of delay to road users; regulatory requirements; emergency response issues; accident records; compliance with regulations; countermeasures and their effectiveness; and possible areas for future research.

NOMENCLATURE

Occupied or blocked crossing: crossings where trains are standing or moving slowly; or switching over the crossing; or signalized crossings where the warning system is operating, sometimes excessively.

Signal pre-emption: a system where the normal road traffic signal cycle changes to facilitate clearance of traffic moving in a critical direction

Turnout: a location where trains can be switched from one track to another

State anger: a temporary emotional state

Trait anger: a general tendency to react angrily to perceived situations

CROR 103: Canadian Rail Operating Rules, Rule 103

FLB: flashing lights and bell signals

FLB&G: flashing lights, bell and gates

USDOT : United States Department of Transport.

METHODOLOGY

Internet searches as well as library databases, and guidance and information from the Project Steering Committee and other subject matter experts were used in the preparation of this paper. The majority of sources used were research papers, primarily from universities, and in-depth reports from such organizations as: the US Department of Transport (USDOT), including the Federal Highway Administration (FHWA); the Federal Railroad Administration (FRA); the Volpe Institute; and Transport Canada’s Transportation Development Centre. Transport Canada’s Rail Safety Directorate and the Transportation Safety Board of Canada also provided key information, research reports and expert opinion. Overseas information was provided by Irish and Australian safety experts, and from Dutch, German and Australian internet sources.

Some of the human factors information reviewed in this report covering the issues of anger and risk taking was not related specifically to crossing delay issues. However, the particular research information noted may be applicable or transferable to future research on safety issues at crossings where blockages occur.

TYPES OF CROSSING BLOCKAGE AND CROSSING DELAY

STATIONARY TRAINS AND SLOW MOVING LONG TRAINS

This type of blockage can have several causes: trains in single track territory waiting in a siding for a meet with a train travelling in an opposite direction or to allow a faster or higher priority train to pass; trains stopped at passenger stations; slow-moving long trains entering or leaving a rail yard; trains stopped at a crew change point; and trains having become immobilised for mechanical or other reasons. Additionally, trains are sometimes too long for the available siding, and as a result it is hard to ensure that the meet is executed expeditiously. All of these situations can lead to road user frustration and pose challenges to emergency responders. During periods of high rail traffic demand, rail line capacity constraints can compound these stresses.

EXCESSIVE CROSSING WARNING SIGNAL OPERATION

There are many railway crossing locations where the signal track circuits use prediction software to monitor train speed and subsequently provide a consistent duration of signal operation. Because they allow a more consistent, and predictable, signal duration, these circuits lead to better road user compliance with signals. Other systems, often installed at locations where there is significant switching occurring, use motion sensors to cease signal operation if the movement towards the crossing stops while on the track circuit. The signals recommence once the train starts moving again, but only if it is moving towards the crossing.

However, a large number of signalized crossings use direct current (DC) track circuits to detect trains. These signals are designed to operate for a minimum time of 20-23 seconds before a train arrives. However, this only applies to trains operating at the maximum permissible track speed. If a slow freight train is approaching a crossing equipped with DC track circuits, the signal operating time can be far longer than the design time. Excessive operation in the context of Canadian crossing signal installations is considered to be operation for more than 35 seconds over the design time operation for signalized crossings without gates, and more than 55 seconds for crossings with gates [3, s.20.4]. At the same time, many road users interpret any operation over 30 seconds to mean that they can proceed across the tracks [4]. This means that many crossings equipped with DC track circuits may pose a risk to road users, in that they will have low credibility if there is a large variation in signal operation time before a train occupies the crossing. The Transportation Safety Board of Canada made a finding related to this credibility issue in the investigation of a 2010 crossing accident in Edmonton, Alberta [5].

Another factor that can lead to excessive warning signal operation is that of second trains. In multiple track areas, if a crossing warning system continues to operate after the passage of a train and if a second train is on another approach circuit, the signals will continue to operate until that train has passed over the crossing. At crossings using DC track circuits, the duration of operation can be lengthy, as can also be the time between the exit of the first train and the entry of the second train onto the crossing.

Technical failures of signals are normally few and far between, but they do occur. For example, slush and salt on crossing surfaces can affect the systems and broken wires can also cause the systems to "fail safe" and operate excessively. As will be discussed later, these situations can lead road users to question the signals' reliability and credibility, because of their inconsistency of operation.

RAILWAY SWITCHING OPERATIONS

Switching operations over crossings can block road users for far longer than 5 minutes. Transport Canada safety inspectors have advised that switching operations can sometimes last longer than 30 minutes. Switching operations around stations, rail yards or sidings, can all involve movements over crossings for extensive periods of time. Signals may continue to operate throughout this process if a train is not occupying the crossing but is still on a track circuit. The resultant situation is that many road users may consider that they must not cross, or believe they are not able to cross safely. For example, at a signalized, non-gated crossing, school bus operators (who are typically required to stop at all crossings) might refuse to proceed over a crossing when there is switching in the area, whereas many other road users behind the bus might deem it safe to proceed after stopping and checking for an approaching train.

FREQUENT CROSSING SIGNAL OPERATION

Besides the above-mentioned second train operations, frequent operation can occur in areas of commuter train operations during peak periods, or during switching operations at the throat of rail yards. When this sort of operation takes place in large or small urban areas and the crossing is near a highway intersection, long queues can form which end up backing across the intersection. This may lead to a collision between a train and a vehicle backed-up onto a crossing, with a resultant increased delay to road and rail traffic, property damage and road user injury or fatality.

HUMAN FACTORS

Although this review found little human factors information specifically on road user behaviour at blocked crossings, there is considerable information available on behaviour at crossings where there is excessive signal operation or where aggressive drivers or pedestrians make risky decisions either before a train enters, or after it exits, the crossing.

Additionally, there is literature which identifies the tendency for various demographic segments to take increased risks. Other literature also examines people's perceptions of waiting times and how these perceptions can be altered. The sources of this human factors research involved surveys, questionnaires and laboratory simulations.

CHARACTERISTICS OF CROSSING USERS

Crossing users are of all ages and consist of vehicle drivers, pedestrians, and users of other human-powered devices such as bicycles, wheelchairs and roller blades. They comprise travellers who are on journeys to work, school, business, recreation or for pleasure, as well as workers already on business trips such as commercial drivers. The proportions of each traveller type varies by time of day, type of road function and land use in the area.

Road user behaviour at blocked crossings can vary. For example, motor vehicle operators are essentially trapped, with no alternative but to wait, or perhaps make a U-turn and detour to another crossing. On the other hand, pedestrians and other non-motorized vehicle users have the same two options, but additionally have the very risky option available of deciding whether to climb through, under, or over rail equipment. These non-motor vehicle road users are therefore more exposed to risk of injury, dependent on their decision making process.

AGE AND GENDER DIFFERENCES

Metaxatos et al.'s [6] unpublished (at the date of writing) 2013 research report: Non-motorist Safety Attitudes and Revealed Behavior at Rail Grade Crossings used 10 selected crossings in northeastern Illinois for a study and survey of non-motorist behaviour. One of their findings was that "trespassers" at crossings are predominately male. The report also notes that females are more safety conscious than males, and that young males under 21 years of age are more likely than other groups to cross against activated warning signals. This compares with the Volpe Center's literature review [7], which cited research results on driver behaviour at crossings in Michigan in 1998 revealing that drivers aged between 25 and 35 years were observed to commit more driver violations at crossings than any other age group.

The Volpe report [8, p.59] citing Abraham and Datta, also revealed that male drivers were involved in 77% of fatal highway accidents and 64% of violations at grade crossings, and that they represented the majority of risk-seekers. The report states that personal values influence young drivers' motivation to comply with traffic laws more than external factors such as punishment.

In comparison, Calgary's Cognitive Ergonomics Research 2002 report for Transport Canada [9] revealed that the Canadian male driver population also committed more violations at crossings when compared to the female driver population, whatever the age range. The overall proportion of violations is approximately three male crossing violations for every female violation.

PEDESTRIAN BEHAVIOUR

The Metaxatos et al. study [6, p.7] on non-motorist safety attitudes at a sample of Illinois crossings found that almost half of the 312 pedestrians surveyed stated they would cross the tracks: if they felt there was enough time; if others were crossing; if they were in a hurry; if they were annoyed by having to wait; or if they could not see a train coming.

Freeman et al.'s [9] literature review on pedestrian behaviour at level crossings reported that males, school children, older pedestrians and those with disabilities are disproportionately represented in railway crossing fatality databases. However, little is known about the causes of train-pedestrian collisions when compared to train-vehicle collisions, i.e. whether the collisions result from engaging in deliberate violations or from errors.

The USDOT's Federal Highway Administration (FWHA) [10] noted the relative ease with which a pedestrian can enter a crossing even if pedestrian gates are provided and have descended. It noted four contributing factors that may motivate pedestrians to occupy or cross the railway right of way, two of which may apply at crossings: railways often act as physical dividers between important, interrelated elements of communities; and passengers frequently taking short cuts before boarding a train.

According to Metataxos and Sriraj's [11, p.37] research on pedestrian / bicyclist warning devices at crossings, active warning signs at grade crossings are noticed more frequently than passive signs, independent of gender or frequency crossing use. Additionally, younger users (those under 30 years of age) are more likely to pay attention to active signs, whereas older users notice passive signs more frequently.

CRITICAL WAIT TIMES

There are two kinds of critical wait time for road users delayed at crossings: the duration of time before arrival of a train at a signalized crossing; and the duration of time that a stopped or slow-moving train is blocking the crossing. Although there was relatively limited information identified from the literature search on both types of delay, some useful data was found.

Pripfl's [12, slide 24] presentation on human factors issues at level crossings, referring to literature reviewed identified that a waiting time of two minutes' signal activation before train arrival was acceptable. This "acceptable" time for German road users appears to be significantly longer than that in North America, where excessive signal operation is deemed by Transport Canada [2] to be 35 seconds or more before the arrival of a train. It is not clear if the difference is cultural in nature, or related to differences in signal systems and the information available to road users.

While no specific delay time duration was identified as critical to the level of annoyance of road users, Hall and Somers [13] have defined a long wait time as being that of five minutes, as have Iorio et al. [14]. This compares with a Monash University driver simulation study by Edquist, Rudin-Brown and Lenné [15]. One finding in the study was that just one of the 52 study participants was prepared to wait as long as 5 minutes at a crossing where signals were operating but no train was present, after which time that person would then cross. The other 51 participants indicated they would wait no longer than three minutes before crossing. The previously referenced Volpe Institute report [7, p.67] cited a Michigan survey of 1,200 residents which revealed that 14 percent of drivers would drive around the gates of a crossing with a train in sight, and 10 percent of drivers considered it exciting to beat the train across the tracks. This is similar to information provided in the Pripfl presentation. This latter presentation cited a 2006 German study by Ellinghaus and Steinbrecher, which revealed that 25% of drivers and 40% of cyclists and pedestrians were willing to cross tracks shortly after the lights start operating; and that one third of road users in Germany are regularly annoyed by long waiting times (defined as 15 minutes or more) at crossings.

The Michigan Department of Transportation conducted a study of driver behaviour at rail-highway crossings in 1998 [16]. Questionnaire responses presented in the study indicated that a majority of drivers take risks when the credibility of traffic control devices is low. Two of the several reasons for this behaviour are that the traffic control devices are active for extended periods of time while the train is not in sight, or the train is too slow. The research also found that vehicle drivers familiar with a specific crossing violate the signals more often than drivers who do not live in the immediate area.

RESEARCH REGARDING ANGER, AGGRESSION, MOOD AND RISK TAKING

Fessler's research [17] found that women manage anger better than men, as far as risk taking is concerned. Using a gambling scenario for their laboratory research using 59 male and 60 female participants, they demonstrated that while anger increases risk taking in men, women do not typically increase their level of risk taking when angry. Additionally, women reacted to situations of disgust by decreasing risk taking, whereas the same situation did not change male participants' level of risk taking behaviour.

Leith and Baumeister [18] found that negative moods and high arousal can result in high risk, high payoff, and gambling decisions. Embarrassment, which was induced by unpleasant negative noise stresses after the occasion of losing a lottery, increased the preference for a high-risk, high-payoff lottery over a low-risk, low-payoff one. Anger was shown to have a similar effect. The report concluded that bad moods foster risk taking by impairing self-regulation. When people are upset they tend to choose high risk, high payoff options.

Lerner et al. [19] found that whereas fearful people expressed pessimistic risk estimates and made risk-averse choices, angry people expressed optimistic risk estimates and made risk-seeking choices, i.e. took more chances than fearful people.

Regarding research specifically on driver behaviour, most information identified in this review on driver anger came from university research, which used questionnaires and surveys as well as laboratory simulations to assess anger levels and related performance issues. In most cases, the research subjects were volunteer students and employees.

Deffenbacher et al. [20] found, in their surveys of a large sample of university students, that high trait anger drivers have anger triggered by a wider number of situations, experience more frequent anger and display more intense anger than low trait anger drivers. They also found that increased anger and agitation may result in an increased level of impulsive and risky behaviour such as speeding, rapid lane changing and drinking and driving. They did not find any significant gender differences, apart from a tendency for high trait anger males to drive at higher speeds than high trait anger women.

A study by Stephens et al. [21] found, in laboratory driving simulations, that anger increased and mood and driving behaviour deteriorated in drivers exposed to slower lead vehicles, compared with control group drivers who had experienced no impeding lead vehicle. They also concluded that sometimes dangerous driving may result from anger carried over from prior situations where drivers have been delayed. They confirmed that when drivers are impeded they experience anger immediately, whereas the anger effect of time pressure is gradual and cumulative. Both impedance and time pressure were effective in increasing anger and angry mood, and drivers subsequently approached hazards with less caution, and attempted more dangerous manoeuvres. Stephens also noted findings from Björklund, 2008 and Stern 1999 showing that time pressure exacerbates anger when drivers are being impeded and allows fewer situation cues to be used when decisions are made (i.e. less information is considered when making decisions).

The Netherlands' SWOV Institute for Road Safety Research Fact Sheet on Anger, aggression in traffic, and risky driving behaviour [22] revealed that typical situations of aggressive driving include traffic jams, red light delays, or violations committed by others that cause inconvenience. At the same time, according to Fairclough and Spiridon [23], researching driver stress in traffic jams using a laboratory simulation with 29 male participants, traffic delays significantly increase blood pressure, heart rate, and may have consequences for the long-term health of the individual.

The FRA's report on Effects of Active Warning Reliability on Motorist Compliance [24] cites two laboratory tests of experienced drivers exposed to excessive signal operations and the subsequent reduced driver compliance level with the signals. This is supported by Pripfl's [12] presentation, citing US and European literature sources, which both show that unreliable warning times can lead to violations of crossing signals and affect driver expectations negatively.

DELAY PERCEPTION

Although not directly related to road user delay, bus transport studies into waiting time by Dziekan et al. [25], indicate that people waiting for buses overestimate their wait time by around 30-50 percent. However, if real-time schedule information is provided, the perceived difference is minimal. While there is limited, if any, information on road user perception of delays at crossings, bus transit studies in the USA and Europe have identified possible measures to reduce the stress of not knowing at exactly what time buses will arrive. Use of apps for smart phones, telephone call-in lines for schedules, changeable displays, and countdown timers are already operational in many cities.

Dziekan identified the beneficial effects of real time information displays for public transport. Some of the positive effects described in the paper are: reduced wait time (i.e. for travellers with mobile real-time displays who will be aware of scheduled arrival time and plan their arrival accordingly); positive psychological factors, such as reduced uncertainty, reduced stress, increased ease-of-use and a greater feeling of security; adjusted travel behaviour such as better use of wait time or more efficient travelling and a better image of the service provider. The paper also showed that travellers' perceived wait times can be reduced by 20% by using these technologies.

Hickman's research report [26, p.225] referred to the Countdown demonstration project in London in the mid-1990s which conducted research revealing that real-time information on bus arrival times for a single route has significant value to transit passengers, at about 50% of the average passenger fare.

Watkins et al. [27] found that, for riders without real-time information, perceived wait time is greater than measured wait time. Mobile real-time information provided to customers through, for example, their smart phones or other mobile device reduces not only the perceived wait time, but also the actual wait time experienced by customers.

PROXIMITY AND LAND USE

CANADIAN REGULATORY REQUIREMENTS / REGULATIONS RELATING TO BLOCKED CROSSINGS

As noted earlier in the introduction, CROR [2] Rule 103(d) mandates that stopped trains shall block crossings no longer than 5 minutes at one time. After that time, the train has to be moved or split to allow road users to pass over the crossing. However, if trains are continuing to move, the 5 minute rule does not apply.

LAND USE ISSUES

Increasing urbanization and increasing commodity rail traffic inevitably lead to congestion in areas where the two meet. In an ideal world, rail yards and sidings would be located away from communities, and from local institutions and businesses. However, that is impossible to achieve, as rail yards are almost always surrounded by residential, industrial, commercial or institutional land uses, especially in major metropolitan areas such as Canada's largest cities. Since road users have to go to work, to school, or travel for business or pleasure, conflicts will occur.

While these land use changes have been occurring, during the last 30 years railways in Canada and the United States have been streamlining and optimizing operations, from an economics perspective. This has included operating with longer trains. While customer demand on rail freight services has been almost constantly increasing since that time, track capacity and yard capacity have, in many cases, diminished This means that there is more traffic demand on the main line, which can at times conflict seriously with community needs in areas across the country.

COMPARABLE INTERNATIONAL ISSUES

Australia, like Canada, has heavy haul railways and also has similar blockage issues to those occurring in Canada. Australia has regulations on 5 minute maximum crossing blockage time for stationary trains. However, the Australian expert contacted was not aware of any specific solutions to the delay problems [28]. Other countries have issues with crossing blockage and delays, but the European experience is typically problems related to significant delays caused by second train issues.

The earlier referenced [13] Hall and Somers research conducted in Victoria, Australia included mathematical simulation results suggesting that crossing signals interconnected with nearby highway signals and modified commuter train schedules can significantly reduce the blockages and back-up from crossings in urban areas .

Ireland, as an example from Europe, has experienced problems of blockage where crossing gates were down for extended periods, in dual track territory, with two passenger trains in the vicinity of the crossing. It remedied the problems by having the railways rearrange their train schedules such that the trains cross at the same time at the level crossing [29].

The United States is, not surprisingly, most similar to Canada in terms of train and signal operations which cause delays or blockage. However, in the US there is no federal regulation on crossing blockage; each state has its own regulations. State laws on blockages also vary widely. According to the FRA [30], there are 23 states which either have no statute, or else have not explicitly quantified a maximum blockage time. The document identifies 12 states and Washington DC which allow blockages of up to 5 minutes for trains actually stopped on crossings. 15 other states allow 10 or more minutes, including Louisiana, which allows up to 20 minutes blockage where stopped trains block crossings. There are differences in specific details between each state's statute; for example, some have differing requirements regarding the type of blockage, type of train operation, emergency response needs and urban area.

The Compilation of State Laws states that: *The time allowed for blocking varies, but in no case does it exceed more than 20 minutes. A number of states list an exception for emergencies or circumstances beyond the control of the railroad company. That is not to say that the individual cities and towns within those states with no relevant statute do not have an ordinance restricting the blocking of highway-rail grade crossings within their jurisdictions, because they do. Additionally, Illinois' law states that: In a county with a population of greater than 1 million, as determined by the most recent federal census, during the hours of 7:00 a.m. to 9:00 a.m., and 4:00 p.m. to 6:00 p.m., it is unlawful for a rail carrier to permit any single train or railroad car to obstruct public travel at a highway-rail grade crossing in excess of a total of 10 minutes during a 30-minute period, except where the train or railroad car cannot be moved by reason or circumstances over which the rail carrier has no reasonable control.*

The FRA issued a fact sheet related to blocked crossings in May 2008 [31]. The sheet summarizes almost all issues that pertain to crossing blockages as well as identifying possible solutions, including operational and technological ones, to mitigate the problem. The FRA fact sheet notes that the issue of federal vs. state laws is a contentious one. Part of the sheet states: *...the issue of a state's authority to legislate or regulate blocked crossings is highly contentious and still being defined in the courts. Railroads have on occasion mounted "pre-emption" defenses, citing FRA regulations and other federal requirements which they believe take precedence over state laws or local ordinances. Where there is a conflict between the state law and federal rail safety requirements, the courts have found the state law to be pre-empted and, thus, unenforceable.* It should also be noted that, in 2000, a Michigan court decision called into question any non-federal regulation on trains blocking crossings. Despite this, some US railroads have cooperated with affected communities to address the issues, while others have taken advantage of this possible regulatory gap [32].

COMPLIANCE AND ENFORCEMENT

Numerous studies have been conducted across North America on compliance rates at level crossings. These include a study in the province of Alberta [33] researching blockages at signalized crossings, including video-recording the vehicle violations. The Alberta study was designed to assess the effectiveness of automated photo enforcement at grade crossings in the first pilot test of the technology in Canada. A pilot system was installed at a non-gated grade crossing equipped with flashing lights and bell in Strathcona County, Alberta. Warning citations were issued for non-stopping violations. The results demonstrated that there was a 69 % reduction in non-stopping and stop and go violations when photo enforcement was active compared to when it was not. The researchers concluded that automated photo enforcement did reduce risky driver behaviour at the crossing. However, the actual crossing studied had had numerous instances of excessive operation during the eight month study. It is not clear from the report if the original driver behaviour was linked to awareness of that situation.

According to the FHWA [10,p.217], in 1995 at 17 gated crossings in Los Angeles, and in 2000 at four crossings in Illinois, the use of photo enforcement yielded a reduction in violations of just under 50%.

Rescot's [34] 2013 study on grade crossing closure times in Indiana yielded a violation prediction model. The model identified that the variable with the strongest statistical significance for predicting violations of road users going around lowered gates was the amount of advance warning time provided, i.e. the longer the time between lowering of the gates and the arrival of the train, the higher the rate of violations.

The FRA [35] reported on two experiments on crossing signal operations. One experiment measured motorist behaviour in response to false alarms (i.e., the presentation of a warning when no train was approaching); the other examined how motorist responses to signals were influenced by false alarms and missed signals (i.e., the failure of the warning system to signal an approaching train). The results of these experiments found that warning system reliability exerts a predictable effect on motorists: as motorists perceive the warning systems to be less reliable, the more likely they are to violate the warning signal, as they consider there is little risk to their safety. The results indicated that participants were able to detect changes in the reliability of the warning device. As participants perceived the warning device to be less reliable, they were more likely to deliberately ignore it, probably because they perceived little risk to their safety. FRA noted that, from an engineering perspective, the research suggests that incorporating good maintenance practices and correcting signal malfunctions in a timely manner can improve driver compliance.

REGULATIONS RELATING TO CROSSING VIOLATIONS

In Canada the various provinces' Highway Traffic Acts specify that trains have the right of way at a crossing. Additionally, the Canadian Government's Railway Safety Act [36], RIGHT-OF-WAY (Section 26.2) states that*: The users of a road shall give way to railway equipment at a road crossing if adequate warning of its approach is given.* Transport Canada's Overview of the Railway Safety Act (2002) [37] interprets this in the following way: *Users of a road are required to give way to railway equipment at a road crossing when adequate warning of its approach is given. Adequate warning is generally accepted to mean compliance with all applicable rules, regulations, standards and orders.* It adds a caveat that*: such right-of-way exists only if adequate warning of the train's approach is given.*

At the time of preparing this paper, Transport Canada was in the process of proposing new Grade Crossings Regulations with the objective of reducing the frequency and severity of accidents, thereby saving lives and preventing injuries and derailments at federally-regulated grade crossings.

TSB ACCIDENT RECORDS AND INJURIES SUSTAINED AND CHARACTERISTICS OF THOSE INVOLVED (GENDER, AGE, TRIP PURPOSE IF POSSIBLE)

The Transportation Safety Board of Canada (TSB)'s Railway Occurrences Database System (RODS) stores information on federally regulated railway occurrences. Data fields in RODS include: accident location; railway; track and train type; train and road speed; crossing characteristics, train and road vehicle occupant injuries and fatalities; and a summary of the occurrence. A review of the RODS database was conducted. Records on accidents at blocked crossings that were identified were limited to situations involving pedestrians and other non-motorized road vehicles. This data is limited, with only four records identified for a period of 34 years, using blocked or blockage as the search words. There is just one accident record (TSB investigation no. R02C0019) of a vehicle striking a stationary train, two records of drivers being struck after having been blocked-back from an upstream road intersection onto a crossing; and one record of a driver struck when upstream road traffic was blocked back because of a train on another company's nearby tracks.

TSB identified 29 records in RODs using the key words of climbing through, climbing over, climbing under, crossing, and trespasser. The records revealed that some of these non-motorists were travelling in fairly large groups, some were climbing on moving equipment and some were initially moving across the tracks when a train started to move. Several involved school-aged children. Whether or not they are classified as trespassers or as a crossing accident, it is likely that similar events to these could occur at blocked crossings. The records showed that the results of this type of accident are often severe, with many resulting in loss of parts of limbs or crushed limbs, as well as one fatality. The injuries were usually a result of a pedestrian having a foot crushed in a coupler, or a part of a limb severed by being run over by a wheel.

SOME POSSIBLE SOLUTIONS TO MITIGATE OR REMOVE DELAYS

Florida's Department of Transport [38] did extensive work investigating the potential for using traffic signal system software platforms for pre-emption of road traffic signals. They modelled upstream pre-emption signals for triggering what they termed pre-preemptions at downstream intersections along the railway corridor. Their simulations found that the pre-preemption strategy can effectively reduce average delay, average number of stops, and average queue length on the arterial roads near a railroad crossing. The Florida DOT suggested road traffic volumes and time of blockage criteria for applying this pre-preemption strategy.

Hall and Somers's [13] Australian simulation model demonstrated that interconnection of crossing signals, upgraded track circuitry and adjusted highway traffic signal phases to clear traffic through the crossing reduced congestion by around 15% at gated crossings. Scenarios that reduced the length and variability of crossing closures also resulted in not only lower average travel times, but also less spread in the travel time results. In the United States, Caltrain has also done work on ways to minimize time that gates are down while rail traffic is increasing [39]. Both of these simulation models were for passenger and commuter operations.

FRA [1] describes video systems and other communications technologies that can be used by the public and emergency responders to identify blocked crossings and alternative routes. For example, it describes a blockage detection system, with examples of its application in California and Texas. It also describes the use of active signs to alert drivers to expected blockages.

Australia's Centre for Technology at La Trobe University has done research into developing a technology-based solution to improve safety at level crossings [40].Their project uses short range communication wireless technology to provide vehicles and drivers with a 360 degree level of awareness of the surrounding traffic situation. The technology establishes wireless communication between trains approaching a level crossing and vehicles approaching the crossing. If the system detects the possibility of a collision, a warning message is presented inside the driver's vehicle. The system has undergone large-scale field trials in both regional and urban operations. The university claims that the system is low cost and can be implemented quickly. While not directly applicable to road users who find themselves already at a blocked crossing, some of the technology might be transferable to display alternate routes to drivers approaching, but not yet at the crossing.

Intelligent Transportation Systems (ITS) can be used for in-vehicle warnings or used on smart phones, with real-time monitoring and intervention techniques These systems have been tested in Canada and Australia.

Regarding variable message signs, the City of Montreal has just introduced a $150,000 emergency warning message sign tied in with a laser system which detects and displays an immediate warning to over-height trucks at a restricted height railway bridge [41]. It may be possible that some of this technology is transferable to warning systems for pedestrians or cyclists approaching a blocked crossing or crossing about to be blocked.

There is a potential for variable message electronic signage for alternate routes that could be used in small and large communities. Additionally, successful tests have been conducted in the US to link fire departments with rail traffic control centre displays and show crossings that are either blocked or potentially blocked and also displaying the nearest clear crossings.

Other options which would specifically involve changes to train operations are: relocation of crew change points, installation of power switches at turnouts, increase in design speed of turnouts, twinning of tracks on principal main lines, relocation of tracks away from cities, shorter trains, and rescheduling of trains. The upcoming introduction of positive train control systems in North America may also offer better ways of managing train meets and the possibility of communicating blockage and delay information to road users.

BENEFIT – COST ANALYSIS OF PROBLEM MITIGATION

Because there is currently a lack of reliable data on the levels of congestion at crossings, a completely realistic cost-benefit analysis on the impact of congestion at crossings cannot be done. However, the following approach uses several assumptions to offer a rough idea of some of the potential benefits and costs. Sensitivity analyses can be done by changing the assumptions for the variables.

Assume a crossing in an urban area with a peak hour road traffic demand of 1500 vehicles per hour and a daily 3 hours peak period (1 ½ hours in the morning and in the afternoon). Assume that the daily peak period blockage results in 30% of available road capacity being eradicated. That represents 1500x3x0.3 vehicles being delayed during peak periods. A rough estimate of the delay cost during a weekday peak period is one-half the product of total hours of delay and the number of vehicles delayed, times the value of lost time (say 70% of the 2013 average hourly wage of about $23/hour), times the vehicle occupancy rate, assumed to be 1.3 persons. The value of one-half is used as an estimate in lieu of developing a queuing model, which is outside the scope of the current effort. Using these figures, the peak period daily delay cost is around 1500x3x0.5x0.3x0.7×$23×1.3 or just over $14,000 daily. Using this latter figure as a conservative estimate for the additional delay costs for non-peak period traffic (the other 21 hours of the day), the daily weekday delay cost is just over $28,000.

Some other costs not included in this simple example are fuel consumption cost, fuel emissions cost and cost of missed appointments. Under this scenario, over the duration of a year, assuming 220 working days and the same frequency of crossing blockage, the value of lost time to road users would be around $6.22 million. Hall's simulation for crossings in Melbourne indicated that signal improvements and train scheduling could reduce road user delays by about 10 or 15 percent. If that technology, or a modification of it, or some equally effective, but other approach was suitable for some Canadian situations, then cost savings of improving signal pre-emption and track circuitry would be between $622,000 and $933,000 annually. Ignoring the ongoing incremental maintenance costs, but also ignoring benefits such as reduced road user stress, reduced accident level, reduced time-related impact on business operations, improved emergency response capability and reduced pollution, and assuming the cost of the modifications is $5 million CAD, the payback period for the investment would be somewhere between 5 1/2 and 8 years.

Comparing this to a grade separation, with, say, costs of $10M to $15M on average, under the same delay conditions as above, all traffic would be free flow over or under the tracks. As a result, these conditions would provide no delay to road users at all. Therefore the payback for the investment would be even shorter, so long as there was no movement of the congestion problem downstream to another location. Benefits to the railway and road users would accrue, with easier operations on the rail side and reduced delay, improved ease of emergency response, increased traveller productivity, lower pollution and fuel costs, and lower stress levels for road users.

Changeable message systems cost $10-15k per unit. While no detailed analysis is given here, benefits would include: reduced stress for road users; identification of alternates; and the ability for road users to change their route and continue their trip rather than wait at the crossing.

DISCUSSION AND CONCLUSIONS

This literature review has revealed that the delay problem related to blocked crossings in Canada is growing and is country-wide. The situation has evolved as a result of railway companies continually improving their operations and economic efficiency, which has unfortunately had an adverse effect in terms of delay on road users at many grade crossings. There is research literature on the effects of stress on motorists as well as research on the behaviour of road users at level crossings and elsewhere and their propensity to manage risks. The delay effect of blocked crossings on many road users is immediate and negative. There are also different effects on road users depending on the specific types and locations of railway operations.

There does not appear to be any literature which identifies a specific wait time as the critical point at which the majority of delayed road users become angry or frustrated. While the Stephens study [16] indicated that anger can be immediate for impeded drivers, it also stated that anger can increase gradually when one is under time pressure. Both of these findings imply that the shorter the delay, the better. While maximum crossing blockage times are prescribed in regulations and in some legislation (varying from 5 to 20 minutes for stationary trains) it is clear that for road users the shorter the time, the better.

There have been some worthwhile experimental initiatives, such as the linking of traffic control centres with emergency response centres, in-vehicle warning systems, and transit passenger variable warning signs. Implementation of these approaches can alleviate stresses on those who are about to be delayed, or who are already delayed. Possible railway-related solutions or mitigating actions include shorter trains, track twinning, track circuit upgrades, turnout upgrades and revised schedules, all of which offer opportunities to shorten delay times. From a long-term infrastructure perspective, grade separations are expensive, but can be very effective in the long run as they have a reasonably short payback period.

Rough estimates of benefits and costs of various alternatives, based on several stated assumptions, indicate that there could be several ways to mitigate or reduce the delay problems and also reduce road user stress. However, any solution to the problem should be based on the specific issues that apply at the particular location.

ACKNOWLEDGMENTS

The authors would like to acknowledge the valuable input from the Project Steering Committee

Amer Afridi, City of Surrey, BC
Donna Chan, City of Richmond, BC
Brian Dreika, Transport Canada
Mike Lowenger, Railway Association of Canada
Jay Rieger, Transport Canada
Mike Regimbal, Operation Life Saver
Daniel Rubenstein, Federation of Canadian Municipalities
Missy Rudin-Brown, Transportation Safety Board
Derek Simenac, Transport Canada
Kyla Zimmerman, Transport Canada

REFERENCES

1. Impact of Blocked Highway/Rail Grade Crossings On Emergency Response Services, Federal Railroad Administration, August 2006
2. Canadian Rail Operating Rules, February 26th, 2008 (TC O-0-93), Transport Canada
3. Transport Canada RTD 10 Road/Railway Grade Crossings Technical Standards and Inspection, Testing and Maintenance Requirements, October 24, 2002
4. Berg et al. (1982) Causal Factors in Railroad-Highway Grade Crossing Accidents Transportation Research Record No. 847, Accession Number: 00368154

5. TSB Rail Investigation Report R10E0046, www.tsb.gc.ca

6. Non-motorist Safety Attitudes and Revealed Behavior at Rail Grade Crossings, Paul Metaxatos and P.S. Sriraj, Urban Transportation Center, University of Illinois at Chicago, Stephen Laffey, ICC, (M/C 357)pp. 6-17

7. Highway-Railway Grade Crossing Research, TP13938E, A Human Factors Analysis of Highway-Railway Grade Crossing Accidents in Canada, prepared for Transportation Development Centre, Transport Canada by Cognitive Ergonomics Research Laboratory, Department of Psychology, University of Calgary, Sept. 2002

8. Driver Behavior at Highway-Railroad Grade Crossings: A Literature Review from 1990–2006

U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center Cambridge, MA 02142-1093

9. Understanding pedestrian behaviour at railway level crossings: is there a need for more research? TRID Accession Number: 01503233 Road and Transport Research, Volume 22, Issue 3, 2013, 72-82 Freeman, J Rakotonirainy, A Stefanova, T McMaster, M 2013

10. Federal Highway Administration, Railroad-Highway Grade Crossing Handbook - Revised Second

Edition, 2007, pp.31,32

11. Pedestrian/Bicyclist Warning Devices and Signs at Highway-Rail and Pathway-Rail Grade Crossings, Metataxos and Sriraj, Urban Transportation Center, University of Illinois at Chicago, April 2013

12. Human Factors Issues at Level Crossings: Some facts and theories from literature (presentation),Dr. Jürgen Pripfl, University of Vienna, kuratorium für verkerssicherheit (trustees for work safety)

13. Investigating Efficiency at Level Crossings: Simulation of Road and Rail Signalling Improvements, Matthew Hall, VicRoads, Australia Andrew Somers, ARRB Group, Australia.

14. Life Momentum at Level Crossing: Human Factor, Road-Rail Safety Policies, Available Technologies. A Cross-sectorial Challenge playing a Rewarding Role for the Upgrade of Safer Mobililty Options, Iorio, De Marco, Cosciotti, Level Crossing 2012, London, 8 – 10 October, 2012

15. Advances in Traffic Psychology, October 2012: Ch. 22,Road Rail Level Crossings: Expectations and Behaviour, Edquist, Rudin-Brown and Lenné, Monash University Accident Research Centre pp.251-258

16. Driver Violations at Rail-Highway Crossings and Crash Experience, TRID Accession Number: 00807096 Michigan Department of Transportation 1998

17. Daniel M.T. Fessler*, Elizabeth G. Pillsworth, Thomas J. Flamson University of California 2003 c Angry men and disgusted women: An evolutionary approach to the influence of emotions on risk taking, 2004 Elsevier Inc.

18. Why Do Bad Moods Increase Self-Defeating Behavior? Emotion, Risk Taking, and Self-Regulation Leith and Baumeister, Case Western Reserve University , copyright 1996 by the American Psychological Association, Inc.

19. Lerner et al: Fear, Anger, and Risk, 2001

20. Deffenbacher et al: Anger, Aggression, and Risky Behavior: a Comparison of High and Low Anger Drivers, 2002, 2003 Elsevier Science Ltd.

21. Stephens et al: Anger-congruent behaviour transfers across driving situations 2011 Psychology Press, an imprint of the Taylor & Francis Group.

22. SWOV Fact sheet: Netherlands' SWOV Institute for Road Safety Research, November 2012

23. Fairclough and Spiridon International Journal of Psychophysiology, May 2012 pp.188-193, Cardiovascular and electrocortical markers of anger and motivation during a simulated driving task,

24. Effects of Active Warning Reliability on Motorist Compliance at Highway-Railroad Grade Crossings U.S. Department of Transportation Federal Railroad Administration RR 09-04March

25. Dynamic at-stop real-time information displays for public transport: effects on customers Katrin Dziekan *, Karl Kottenhoff 1 Transportation Research Part A 41 (2007) 489–501, Elsevier 2006

26. Passenger Travel Time and Path Choice, Implications of Real-Time Transit Information, Mark D. Hickman and Nigel H.M. Wilson, Pergamon, Code 0968-090X(95)0007-0, Copyright 3; 1995 Elsevier Science Ltd.

27. Where Is My Bus? Impact of mobile real-time information on the

perceived and actual wait time of transit riders Kari Edison Watkins, Brian Ferris 2010

28. Source: Terry Spicer, RLX Safety International Pty Ltd, Victoria, Australia

29. D J Murton, Government of Ireland, Rail Accident Investigation Unit.

30. USDOT: Compilation of State Laws and Regulations affecting Highway-Rail Grade Crossings, 5th Edition, October 2009

31. Federal Railroad Administration: Trains Blocking Highway-Rail Grade Crossings Fact Sheet, May 2008

32. Stephen Laffey, Illinois Commerce Commission, Springfield, Illinois

33. TDC 14517 2006 Highway-Railway Grade Crossing Research, Pilot Evaluation of Automated Grade Crossing Signal Enforcement, TranSys Research Ltd., December 2005

34. Estimation of At-Grade Railroad Crossing Gate Down Times, Motorist Delay, and Crossing Violations in Northwest Indiana 2013 Rescot, Robert Andrew TRID Accession Number: 01478906

35. Effects of Active Warning Reliability on Motorist Compliance at Highway-Railroad Grade Crossings, Federal Railroad Administration, RR 09-04March 2009, TRID Accession Number: 01142757

36. Railway Safety Act (1985, c. 32 (4th Supp.))

37. Overview of the Railway Safety Act 2002, Transport Canada

38. Coordinated Pre-Pre-emption of Traffic Signals to Enhance Railroad Grade Crossing Safety in Urban Areas and Estimation of Train Impacts to Arterial Travel Time Delay, BDK85, Florida Department of Transportation, Jan.2014

39. Caltrain / HSR Blended System Grade Crossing and Traffic Analysis (presentation), Local Policy Maker Group Meeting, May 2013, http://www.caltrain.com/Assets/Caltrain+Modernization+Program/Presentations

40. http://www.latrobe.edu.au/technology-infusion/innovation/transport/improving-safety-at-level-crossings

41. CBC National News 2014.03.02