EVALUATION OF COMPLEX AT-GRADE RAIL CROSSING DESIGNS USING A DRIVER SIMULATION

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ABSTRACT

This report deals with the unique and first time application in Canada of a driver simulator to assess a complex at-grade rail crossing design. Based on recommendations from a road safety oriented peer review of a proposed upgrade design of a railway grade crossing in the City of Ottawa, the purpose of this simulation was to optimize the positive guidance offered to drivers using the crossing and associated roadway elements, by designing a more understandable, visible and driver-oriented approach environment.

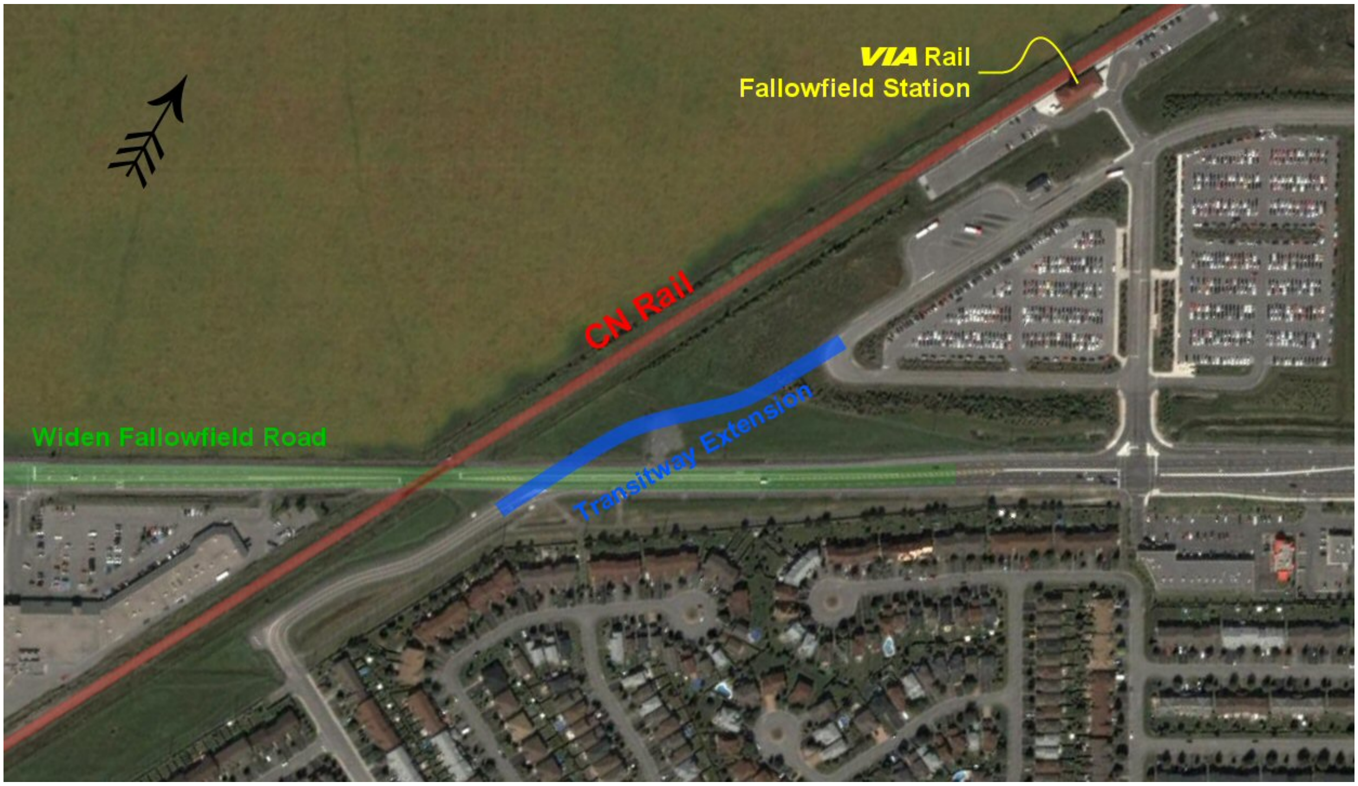
The first section of this paper provides an overview of the existing grade crossing environment and the challenges created by planned road network and development changes in the vicinity of the crossing. The technical complexity and features associated with the proposed design solution that lead to the decision to use a driver-simulator approach to the evaluation of positive guidance and warning systems at this grade crossing are also discussed. In the second section we discuss the data and information requirements necessary to construct the computer model for insertion into the driver simulator – and the particular challenges encountered in meeting these needs. The penultimate section of the paper details the specifics of the simulator study design, with a specific focus on the human factors methodology and considerations used to evaluate the performance of drivers within the proposed crossing environment. Observational driver behaviour and eye movement measures collected during participants' drives are examined and key findings of the study are summarized. The report concludes with a discussion of the advantages, limitations, and challenges associated with using a driver simulator approach to evaluating real-world application scenarios.

1 INTRODUCTION

1.1 Background

In 1995, as part of the ongoing development of their road and transitway system, the predecessor organization to the City of Ottawa (The Regional Municipality of Ottawa Carleton) undertook two related environmental assessments (EA): one for the Southwest Transitway Extension from Baseline Road to Barrhaven; and the second for the widening of Fallowfield Road from its current two-lane state to an initial four (and ultimately six) lane cross section.

Figure 1: Planned road network changes



In the course of these EA's, initial consideration was given to the grade separation of the rail crossing and the transitway. Subsequent geotechnical investigations, community consultations, and the study of other alternatives led to the proposal to construct the Fallowfield Road railway crossing and the transitway as a combined at-grade facility. A number of alternative designs for these crossings were completed and evaluated by others. In the course of that work, a preferred design approach was selected and the decision was taken by the City of Ottawa to commission a panel of experts to carry out a safety-based peer review of that option.

1.2 Traffic and Cross Product

The current average annual daily traffic (AADT) on Fallowfield Road at the crossing is in the order of 20,000 vehicles. Twelve trains per day use the subject crossing. Within five years, volumes are expected to grow to an AADT of just under 23,000 vehicles. At that time, the train volume is expected to be 16 trains per day.

At present, the most commonly used warrant considered for grade separating a railway from the roadway, is what is referred to as the “cross product rule”. This benchmark indicates that when the product of the AADT times the number of trains per day reaches 200,000, consideration of a grade separation should be undertaken. Such consideration usually involves a detailed engineering study.

The volumes of vehicle and train crossings currently using the grade crossing translate to a cross-product of 240,000. With projected five-year horizon traffic and train volumes, this value rises to 368,000. It is important to note that the benchmark is not meant to be taken as a justification for the grade separation, but as a signal that consideration should be given to undertaking the necessary detailed work to assess this need. The recognition that detailed engineering studies are required as the basis for reaching a decision on whether or not a grade separation can be recommended is virtually universal in the relevant North American technical literature.

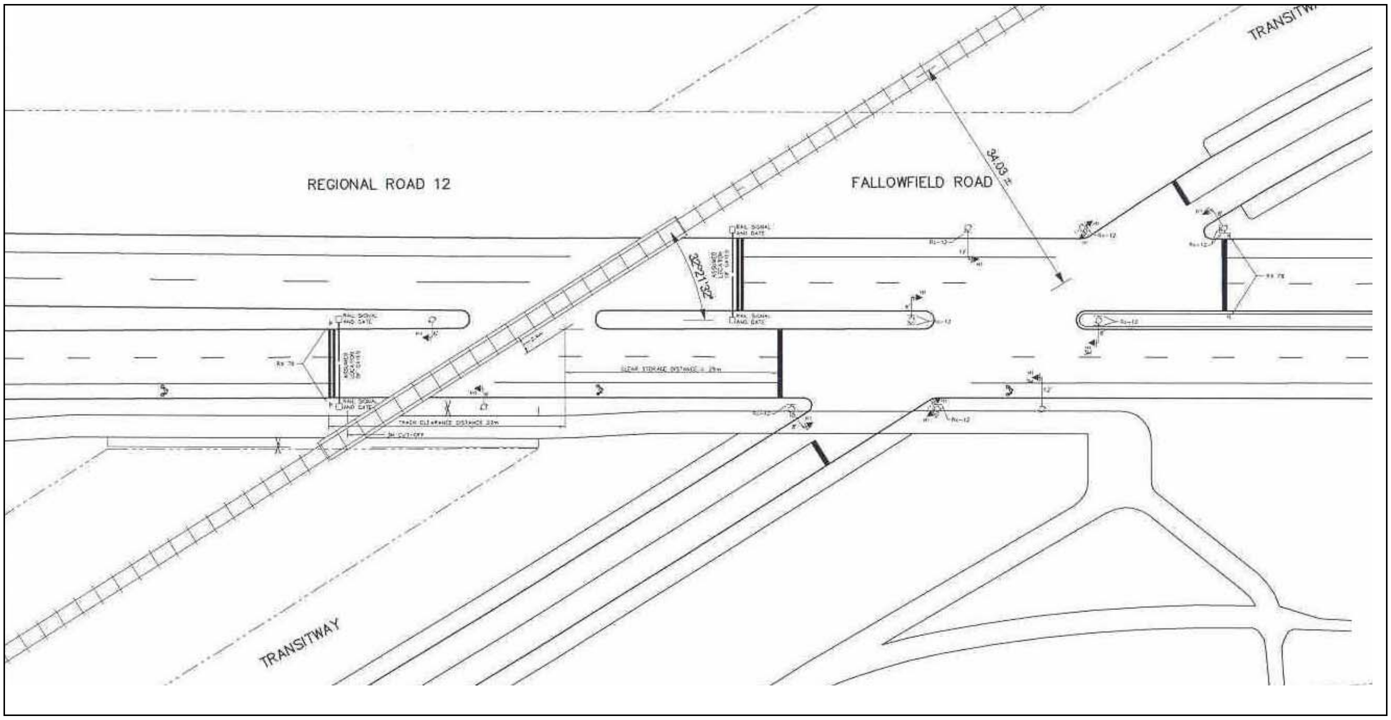
The decision to proceed with an at-grade crossing was taken following detailed engineering and economic analysis by others. The peer review represented a second and supplementary level of study that recognized the need for particular prudence in proceeding with an at-grade crossing under these circumstances.

1.3 Selected design option

The selected design option accommodated the widening of Fallowfield Road to a full four lane cross section and placed the north/south transitway crossing of Fallowfield Road on an alignment parallel to the CNR tracks at an offset distance of approximately 30 m. The Transitway is a north/south, two-way, through intersection with no turns permitted. It will be used only by buses and is controlled by a full traffic signal that is subject to pre-emption by the railway crossing warning system. In effect, the transitway is not a public road but is limited to bus traffic only. Full closure gates close the Fallowfield road lanes completely and the recreational path is secured by a set of barriers on each side of the tracks.

Figure 2, below, summarizes the primary features of the crossing plan.

Figure 2: Selected design option



1.4 The Peer Review

1.4.1 Mandate

The peer review was intended to provide an independent technical assessment of the preliminary design work. As with all peer reviews, the intent was to ensure that the quality and depth of the work carried out was in keeping with current practices, and adequately considered and reflected all of the factors that influenced the safety, efficiency, and effectiveness of the grade crossing and the associated road network components.

1.4.2 Findings

The review raised a number of specific issues related to the warning and other positive guidance measures at the crossing, and recommended that a more detailed and specific study of the crossing be undertaken from a human factors standpoint, since the high driver workload created by the complexity of the proposed design was of particular concern. In addition to the simultaneous presence of the two closely spaced crossings of Fallowfield Road (one transit and one rail), the review panel noted that a number of other factors could potentially exacerbate the workload presented to drivers at this location. These included:

- When approaching the crossing drivers are confronted with multiple warning devices. The process of identifying the various warning devices, recognizing the one most relevant to the driver’s situation, reaching the correct decision on what action to take, and implementing that action – all within what could be a very short time interval and in the potential presence of significant traffic and other environmental influences – places great demand on the driver. Providing them with appropriate, clear, concise, and correct guidance was vital to the overall safety performance of the intersection.

- The close proximity of the rail crossing and transitway intersection create what is essentially an elongated intersection. The apparent distance to be traversed is much greater than that which is crossed in a single intersection or railway crossing. Some level of confusion would normally be expected on the part of motorists presented with the traffic signal, the traffic signal stop bar, the rail signal and gate (particularly if not in the down position yet), and the stop bar for the latter.

- The skew angle of the rail and transitway crossings at Fallowfield Road is in the order of 32°. Acute intersection angles of this type require additional effort on the part of drivers to negotiate, thus increasing overall driver workload in the critical approach area to the crossing. The elimination of this skew is not practical and would probably not be cost-effective. Nonetheless, recognition of its presence and influence highlighted the need for exceptionally thoughtful design of warning and guidance measures associated with the crossing.

1.4.3 Recommendations

As a key risk management activity, the peer review panel recommended investigating the potential for improved warning and traffic control measures associated with the grade crossing through a tightly focused study of specific design elements using a driving simulator facility. Findings from this study would be used to design a more understandable, visible, and driver-oriented approach environment to help drivers select the correct information when they need it and reduce the potential for driver error.

Delphi-MRC was engaged to carry out this work utilizing the services of the University of Calgary’s Driver Simulator (UCDS) and Human Factors North.

2 THE SIMULATION

2.1 Overview

The University of Calgary maintains one of Canada's leading human factors research facilities with an emphasis on driver behaviour. The simulator allows study subjects to physically drive a virtual version of a proposed route while sitting in a real mid-sized passenger car and using the entire normal attendant driving controls (brake, accelerator, automatic transmission, etc.).

Within the driving simulator environment, alternative positive guidance systems (signs, warning devices, pavement markings and similar elements) can be created and placed at varying locations. Active controls may also be triggered including crossing warning devices and traffic signals.

With the use of a sophisticated eye camera driver's eye movement were tracked throughout their driving period. The use of the camera, related driver reaction and time observations, and actual outcomes of their driving decisions, allowed relationships to be established between driver's actions and the information they used to make driving decisions. These findings were then used to optimize the positive guidance plan for the grade crossing.

Figure 3: Experimenters' view of the University of Calgary driving simulator

2.2 Model development

Although the University of Calgary maintains an extensive library of urban, suburban and rural roadway environments, warning and regulatory signs and other roadway appurtenance tiles for the development of simulator models, the level of details required for this project necessitated the development of numerous custom built elements. Using plan drawings, video and photographs, the modeling team created a custom built environment to represent the proposed Fallowfield Road design with exceptionally high visual fidelity. This included the preparation of bilingual sign tiles, accommodating programmable traffic signal heads and development of animated grade crossing warning signals and gates. This was a significant effort that required the close coordination of computer modellers, traffic and design engineers, human factor specialists and technicians from the UCDS.

Figure 4: Animated grade crossing gates and warning signals

2.3 Methodology

The simulation process took place in three distinct phases:

1. In an initial process, the proposed roadway design was reviewed in detail and discussed by the consulting team and City of Ottawa technical staff using the driving simulator to help visualize specific changes that led to a refined plan that was submitted for the more detailed driver behaviour testing.

2. A carefully structured and selected group of drivers representing young, middle-aged and older drivers drove the simulated crossing route.

3. Both observational and eye movement analyses were used to develop an understanding of driver behaviour at the crossing.

Each of these phases of the work is discussed separately below:

2.3.1 Refinement of the positive guidance design to be tested

In refining the positive guidance plan to be tested, the crossing was computer modeled, based on drawings, photographs and video and driven by a panel of highway engineers and human factors specialists to determine the effectiveness of a range of sign, signal and roadway treatments. During this design visualization and interaction phase, a number of design decisions were made based on the interactions with the model. The type of modifications made to the design included:

- Movement of signage, traffic control and pavement marking elements to locations where they would more likely be seen and understood.
- Improving conspicuity of rail crossing through the provision of contrasting road surface materials.
- Adjusting the mounting height of specific signs to ensure warning signals were not obstructed.
- Removal and relocation of signs to reduce visual clutter.
- Evaluation of cantilevered rail warning signals.

2.3.2 Selection of test subjects and driving the simulated route

Once the model was finalized it was evaluated by having 48 participants stratified into the age groups of 18 to 24, 25 to 55 and 55 and older, drive through the Fallowfield crossings in both directions. Half of the participants in each group were male.

The 48 participants were required to hold a valid drivers license, be 18 years of age or older, drive a minimum of 10,000 kilometres per year, and have no previous simulator experience. Participants were also screened for simulator sickness susceptibility, visual and physical health and whether they required corrective lenses to drive. Participants in the 18 to 24 and 25 to 55 age groups were not permitted to participate if they wore glasses due to potential interference with eye movement monitoring equipment. Contact lenses were permitted. Those 55 and older were permitted to participate if they wore corrective lenses. This allowance was necessary to recruit a sufficient number of older drivers into the study.

Participants initially drove a 4 minute practice drive in the UCDS to get familiarized with the simulator and become accustom to driving the posted speed limit. The experimental portion of the study involved driving two 15 minute routes with the Fallowfield roadway embedded in each route. The routes were predominately rural and represented the countryside in the area of the actual crossing in Ottawa. During the course of that drive, a number of different events were simulated to determine if any additional design problems could be identified.

Figure 5: Midsize simulator vehicle with full driver control

2.3.3 Observational and eye movement analysis

A number of simulator measures were collected during participants' drives including: velocity, stopping accuracy, the probability of stopping at the crossing when confronted with an amber traffic light in the dilemma zone, and manoeuvre type in response to a stalled truck just beyond the grade crossing. A number of eye movement measures were also collected, including:

- The percentage of drivers who detected the various signs and signals;
- The distance at which the first glance to a traffic sign or signal was made;
- The distance at which the last glance to the signs and signals was made; and
- The total number of glances to signs and signals.

Finally, participants were interviewed at length about how well they understood the crossing elements and whether they had any difficulties with certain signs or signals.

Figure 6: Amber light encountered in dilemma zone while approaching the grade crossing

3 THE UTILITY OF DRIVING SIMULATORS

3.1 General discussion

We found the driving simulator to be an exceptionally useful and effective tool for the final development and optimization of the positive guidance plan for the combined crossing. The simulator's significant advantage lies in it's ability to help us understand how drivers will use the information presented to them in a given roadway context. In particular, it provided quantitative metrics for comparing the impacts of alternative road and traffic control device design on driver workload.

As with all such complex and specialized technologies, the use of driving simulators has both strengths and limitations that must be weighed against the cost, time and potential to address the research questions of interest.

3.2 Strengths

The strengths of driver simulation include the following:

- The ability to control the driving environment and hence eliminate the influence of possible extraneous or irrelevant variables on driver behaviour.

- The ability to collect detailed eye movement data. The use of eye movement cameras allowed relationships to be established between driver's actions and the information they used to make driving decisions. This ability was fundamental to helping us reach decisions on both the presence and placement of certain elements of the final positive guidance plan.

- The elimination of real-world risk in the form of other traffic, buses, and of course the trains themselves.

- Once the model is set-up, there is a cost efficiency to evaluate a range of crossing elements.

3.3 Limitations

The limitations of driver simulation include:

- Driving simulators in general - including the one used in this experiment – are limited in their ability to represents variations in lighting and shadowing patterns. In particular, most driving simulators cannot replicate night conditions with sufficient fidelity to allow testing and evaluation of such situations.

- Driving simulators cannot replicate signing lettering with the full resolution representative of real-life situations. Thus, depending on the size of the sign text, drivers in a simulator may have to wait until they are closer to the sign to read it than they would in a field setting.

- Although – as noted earlier in this section - there is an obvious advantage to eliminating real-world risk from the driving situation that test subjects experience, depending on the situation, in the absence of consequences (such as hitting a train in this case) driver behaviour may not be the same as it is in the real world.

- Drivers are aware that they are being observed and their performance is being assessed. For some drivers, these factors will lead to less cautious behaviour and for others to more cautious performance.

- Signing practices vary from region to region, and as a result, test subjects may behave differently that might otherwise be expected. For example, in Ottawa signage text is displayed in both French and English while in Calgary the sign text is English only. In addition, the red-light camera sign used in Ottawa differs from that which is used in Calgary. As a result, Calgary-based drivers using the UCDS may not be familiar with the meaning of signs from other jurisdictions.

3.4 The need for an integrated multidisciplinary team

These limitations should not be regarded necessarily as “show stoppers”. In most cases, there is simply a need to recognize the existence of key elements that might influence driver behaviour, and to set the experimental design in such a way as to eliminate or reduce their potential. In some cases, supplementary metrics of driver behaviour, post-hoc subject interviews, and other measures can also be particularly helpful in aiding the interpretation of the quantitative data collected in the course of the experiment.

However, the complexity of representing a real-world experience in a virtual world machine does stress the importance of ensuring that the team represents a fully integrated multidisciplinary group with expertise in the real world (in this case: road design, traffic engineering, railway engineering systems and controls), and in the virtual world (human factors specialists with experience in both the use of driver simulators and in real-world human factors road safety situations, and information technology specialists experience in building the necessary virtual world and events to be tested).

4 LESSONS LEARNED

Our experience in this complex and innovative project was both challenging and very satisfying. In reducing things to their essence it is our sense that we took away from the experience four key lessons:

- Driver simulation is an expensive and time consuming process that clearly is not appropriate for all situations. However, for complex or unusual situations associated with high levels of risk, simulation is an effective risk management tool.
- Although there are some limitations associated with simulation, by using an experienced and integrated multidisciplinary team of human factors and driver simulation specialists, engineers, and information technology personnel, real world driving situations can be accurately replicated in a simulator.
- As each project is different and has its own set of specific design challenges, the preparation of a simulator model and the accompanying experimental design are unique. Pre-screening of the model by a multidisciplinary team of experts including engineers, software developers and cognitive ergonomic specialists is essential to producing a virtual world model and testing scenarios that are appropriate and as complete as can be.
- Driver simulation is an effective tool for developing a positive guidance plan that services road users needs as optimally as possible and provides a defensible basis for deployment in the field.

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