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Can road user delays at urban railway level crossings be reduced? Evaluation of potential treatments through traffic simulation

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Abstract

Railway level crossing closures can disrupt traffic flow significantly, especially in peak hours. The current increases in road and rail traffic worsen the situation and can result in congestion known to significantly increase road users' travel times. In this study, seven of the most problematic level crossings around Brisbane, Australia, were surveyed. The effectiveness of a set of treatments was tested and discussed using computer simulation models. The study found that the variability of warning times is the major cause of unnecessary boom gate downtime. Our observations showed that warning times could be reduced by 10-40s on average for each crossing activation at the investigated sites. A major cause for the variability in warning times are trains stopping at stations that are not equipped with express train identification, and actual train speeds being lower than posted line speeds. Various tested treatments were found to be effective at reducing level crossing closure duration and reducing the variability in warning times, resulting in travel times reducing by 7 to 57% for road users, depending on the level crossing considered. This study shows the potential for the short to medium-term treatment of congestion issues at active level crossings, which are necessary with the current increased rail and road traffic flows.

Keywords: Railway level crossing, Road traffic congestion, Traffic simulation, Warning time

Introduction

Peak hours are times of increased activity in transport networks, with high volumes of commuter train traffic, motorists and pedestrians sharing the access to level crossings. During such periods, the operation of actively protected level crossings can disrupt traffic flow significantly (Federal Highway Administration, 2019), and can create hazardous situations particularly close to railway stations due to the simultaneous crossing access requirements from trains, motorised vehicles and pedestrians (Larue & Naweed, 2018). During normal operations, level crossings can be closed for hours every day, leading to significant traffic congestion, in highly urbanised areas like Florida (Florida Department of Transportation, 2011), or in Edmonds, Washington to name a few (Parker, 2016). This issue is likely to grow with the planned increases in both road and rail traffic volumes (Schwartz, 2012). A similar situation is observed in Australia, where the frequency of commuter trains within the Brisbane railway network has led to more trains, and a higher frequency of boom gate closures during peak periods, reaching a frequency of one train every 6 minutes in 2014. This increased the number and length of level crossing operations.

Extended closures of the level crossing due to high train traffic volumes can result in worsened road congestion at the crossing (Naish & Blais, 2014), and this is what has been observed around level crossings on the Brisbane metropolitan train network after the increase in train frequency. Such congestion can result in drivers entering the level crossing without ensuring that they can go through it completely, and in many road users stopping on the crossing, being blocked by traffic ahead: this has been widely observed: in the United States (Coleman & Moon, 1998; Haleem & Gan, 2015), in Canada (Naish & Blais, 2014), in Australia (Larue, Naweed, & Rodwell, 2018) and Europe (Liang, Ghazel, Cazier, & El-Koursi, 2017) and led to an action plan on this issue in Florida (Florida Department of Transportation, 2011).

In Australia, signalling principles specify that the minimum warning time is 28s (-0s, +5s) and that a minimum time of 20 seconds needs to occur between consecutive operations of half booms. These figures may be extended depending on the number of tracks and the types of vehicles using the crossing. These signalling principles are based on giving enough time for the longest vehicle to clear the crossing at the onset of the activation of the flashing lights. Despite following the same safety principles, activations are up to ten seconds longer than the minimum required in other parts of the world such as the US (Federal Highway Administration, 2019), UK (Office of Rail Regulation, 2011) or New Zealand (New Zealand Transport Agency, 2012), the difference being due to Australian heavy vehicles specificities. The technology installed to initiate the level crossing sequence (commencement of flashing lights, closure of booms) dates from a century ago for most crossings: the activation of the crossing cycle is triggered by the passage of a train at a fixed 'strike-in' point on the railway. This is the point at which the minimum warning can be ensured based on the fastest permitted speed (line speed). While passenger trains are likely to operate near this speed, freight trains potentially operate at lower speeds translating to longer warning and closure times. Combined with the increased train frequency and their effects on level crossing closures for multiple trains, warning times may be a key factor leading to the congestion issues at level crossings.

Recent research has shown with a machine learning techniques that, ideally, 62% of the current railway crossings in the US should be either closed or improved (Soleimani, Mousa, Codjoe, & Leitner, 2019). While grade separation is the safest approach, it is not a viable option given the number of crossings and the costs involved with such an approach. There is, therefore, a significant amount of research focussing on prioritising the crossings for upgrades or closures. It is a complex issue, as highlighted by the latest research which has either used a modified non-radial Data Envelopment Analysis to evaluate the safety of crossings and inform cost-benefit analyses for potential countermeasures (Djordjević, Krmac, & Mlinarić, 2018), or combined multi-criteria decision-making models to assist in making complex ranking decisions (Pamučar, Lukovac, Božanić, & Komazec, 2019). As an example, the Level Crossing Removal Project established by the Victorian Government plans the removal of 75 active level crossings in the Melbourne area (Level crossing removal authority, 2020). The estimated benefits from this project are improving safety, by removing the danger of trains sharing a crossing with road users, reducing congestion, improving travel time reliability, and increasing capacity to run more trains on the network.

With such approach, there is a significant focus on prioritising crossings for an upgrade to a higher type of protection, such as using four-quadrant gates or median separators to reduce risky driver behaviour at crossing with long waiting queues (Liang, Ghazel, Cazier, & El-Koursi, 2018), or for removal. Such an approach fails to investigate other options that may be available to improve road traffic in the short to medium term at a lower cost and for a higher number of crossings.

The review of the literature identified the following gaps requiring further investigation: (i) what are the factors leading to road queues at congested urban crossings, and (ii) how is traffic improved at congested level crossings when applying short to medium term options other than protection upgrades or crossing removal? This paper is the first to study current rail level crossing practice and timings to understand the level of disruption of adjacent arterial traffic caused by boom gate operations on level crossings and to quantify the potential traffic improvements as a result of applying different treatments informed by good practice around the world. Those treatments include changes to the road and rail operations and were investigated using computer simulation models, as such models have been shown to be appropriate for modelling congestion during peak hours, (Shafiei, Gu, & Saberi, 2018), long queues at road intersections (Kamrani, Hashemi Esmaeil Abadi, & Rahimpour Golroudbary, 2014), and with various road vehicles types (Giuffrè, Granà, Tumminello, & Sferlazza, 2018), which are characteristics shared by congested railway level crossings.

METHOD

The effects of various treatments for reducing congestion at active level crossings were evaluated through traffic simulations. This study only focused on motorised traffic and did not consider pedestrian or cyclist traffic. Multiple steps are required to build and calibrate a model that replicates boom gate operations and road traffic realistically. Railway level crossings being an interface between road and rail, data is required from both the road and rail perspectives. As those systems are not integrated, it is vital to understand how well the information of those systems matches and how they can be combined. Therefore, the first step of this research was to conduct a manual site survey that captured the situation holistically of seven of the most congested active level crossings with boom gates in a 15-kilometre radius around Brisbane, Australia. Once the data was collected and normalised, a base case simulation was designed and calibrated. A range of level crossing treatments was then added to the simulation for analysis.

Level crossing operation

Road data detection

Road traffic flow, signal phases and timings were obtained for the road adjacent to the level crossing from the road authorities controlling the area of interest in this study. These data were used to determine modelling parameters and to define the time for the data collection so that it occurred during peak traffic times (morning and afternoon peaks), as congestion effects of boom-gate operations depend on the traffic demand at the level crossing.

To ensure that the manual data collection captured the peak hour fully, traffic monitoring data was downloaded for periods without national or school holidays. Based on this information, the timeframe for manual data collection was set to 7 am – 10 am for the morning peak and 3 pm – 6 pm in the evening peak. Each crossing was observed five consecutive workdays for both morning and afternoon peaks.

Rail Data detection and signalling

The rail company operating the level crossing in the project area provided signal plans, location occupancy summaries, and log files from the signal controllers at the level crossings. Based on this information, the operation of the level crossing could be replicated in the traffic simulation model: train frequency, train speed, closures of the level crossing.

Sites Survey

Data collection was separated into two categories: train operations and road traffic. Train operations included the level crossing (warning signal, boom gate, number of trains), as well as the station itself (dwell time). Four surveyors were recording these operations simultaneously, three being at the level crossing, and one at the platform of the adjacent railway station. Figure 1 provides a view of the location of surveyors at one of the seven selected level crossings.

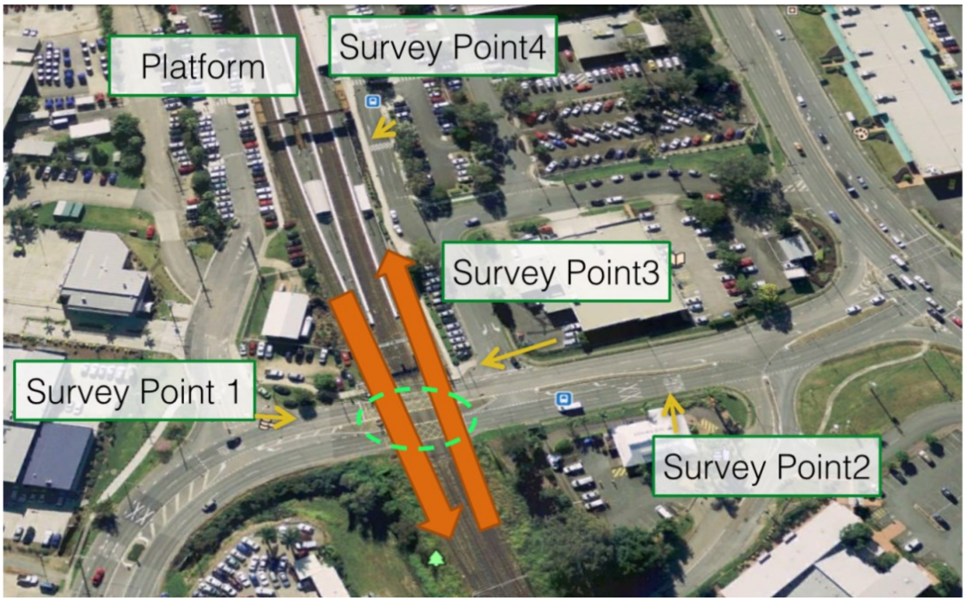


FIGURE 1 Survey points

To capture the necessary events, a mobile application was developed and used. This tablet-based application communicated captured events to a database in real-time through a 3G Internet connection (see Figure 2). When using the application, surveyors were presented with a screen that allowed them to register events by tapping the screen, with the event then represented visually on the screen. Events collected with a synchronised timestamp were (see Figure 2-1):

- Start/stop of flashing warning lights at the level crossing;
- Timing of the operation of the boom gate;
- Trains (front) passing in each direction;
- Train arrivals and departures at the station; and
- Door operation for inbound and outbound trains at the station.

To capture traffic demand at the level crossing, surveyors tapped icons of road user types each traversal of the crossing while the boom gate was open (see Figure 2-2). Types of road users included pedestrians, private cars, commercial cars, trucks, etc.

Once the warning lights at the level crossing start to flash, the surveyor starts recording the number of vehicles in the forming queue behind the stop line, independent of the vehicle type (see Figure 2-3). When the warning lights turn off, the application switches back to counting traffic demand based on vehicle type.

If the queue was unable to clear between boom-gate closures, the surveyors took a snapshot of the actual situation on the road to allow for offline queue length evaluation.

A surveyor was also present at adjacent railway stations and recorded train passage, whether trains stopped at the station, and when stopping, dwell time durations (see Figure 2-4).

All surveyors underwent a training session with the application to familiarise themselves with it. Every surveying team member was also given safety training and a high visibility vest to ensure a safe environment during the data collection process. Figure 3 provides some snapshots of the data collection at the survey sites.

Traffic simulations

The data obtained from the site surveys were used to build a model of the road, train, and boom gate operations in a microscopic traffic simulation using Aimsun (Aimsun, 2017). The simulated network covered the closest intersections upstream and downstream of the level crossing, allowing for the analysis of the operations of the adjacent road network at the level crossing. This approach has already been used to evaluate new interventions for level crossings (Tey, Kim, & Ferreira, 2012). As rail operations were scheduled and controlled independently from road traffic at the site, the train movements were simulated ahead of the traffic simulation using *Brisbane Rail Monitor* data (timetable and speed profile).

The train movements, in conjunction with the signal drawing provided by the rail operator, were used to produce train events in a timeline:

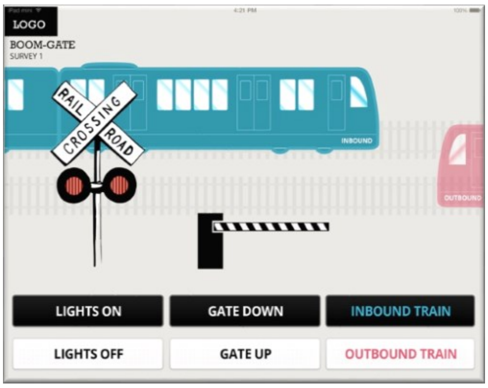
- activation of the control relay (red light flashing)
- timer based boom gate operation
- train passing (as a control to collected data)
- deactivation of control relay (red light stopped).

These events were stored in a train event file that was used as an additional input to the traffic simulation in Aimsun.

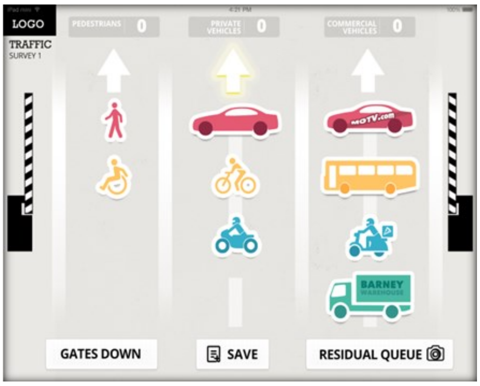
First, the base model was calibrated to replicate the survey data in terms of capacity and proportion of various types of vehicles (small cars, commercial cars, trucks, and buses). Also, some driving behaviour factors were fine-tuned so that acceleration rates, start-up response and boom gates sequences were simulated realistically. This was then followed by the simulation runs for the scenarios in the treatment list of the level crossing (see paragraphs below for treatments considered in this study).

Each scenario was simulated with ten replications, with a 10-minute warm-up to ensure the simulation reaches its steady state. This number was selected based on the minimum number of runs to estimate a mean of a measure of performance as described in Truong, Sarvi, Currie, and Garoni (2016), using an allowable error of 1% at a 95% confidence level.

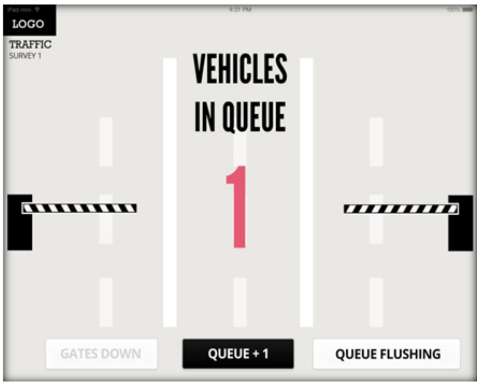
Travel time (TT) was utilised as the key measure of performance. TT denotes the total time that the vehicles spend in the simulation network. The before and after comparison represents the effects of the level crossing on the road traffic system, enabling an assessment of the time that can be saved by the different interventions. The deviation (σ) of TT in the ten simulation replications was also calculated. Each replication used random seeds for traffic generation.



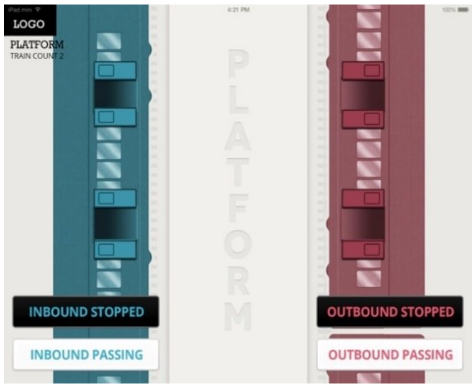
2-1: Level crossing operation



2-2: Road traffic at level crossing



2-3: Queue length



2-4: Train operation at adjacent railway station

FIGURE 2 Interface of the survey app

FIGURE 3 Data collection at the sites

Tested treatments

A review of international best practice on managing level crossing congestion highlighted five different promising treatments for reducing congestion issues adjacent to urban level crossings. The five selected treatments are presented and detailed in the following paragraphs. A traffic simulation approach was selected to identify which treatment would provide the most benefits. The seven surveyed level crossing sites were replicated in a traffic simulator, and the five treatments were modelled and compared to the base condition.

Treatment 1: Restrict vehicle classes at the level crossing

Large and heavy vehicles contribute to both the congestion on roads and the need for longer activations of the crossing. When such vehicles are allowed to proceed through a level crossing, the minimum timing of a level crossing activation cycle has to be increased for they safe traversal of the crossing. Assuming alternative routes are available to such classes of vehicles, restricting the access to the level crossing can be a way to reduce the minimum warning time provided to road users.

At the level crossings considered in this study, the activation cycle was extended by 2 seconds to allow for heavy vehicle traffic. For the implementation of this treatment in the traffic simulation, the additional 2 seconds of warning time was removed, and trucks were banned from the corridor. This scenario was evaluated only at one crossing, which was characterised by a larger amount of heavy vehicle traffic compared to other crossings.

Treatment 2: Road signal pre-emption

Congestion occurs when road vehicles are excessively delayed. At railway crossings, it can be due to overly long and/or frequent closures of the crossing. For level crossings with traffic lights in the close vicinity, it is possible to use pre-emption of the road signal to reduce traffic at the level crossing when it is about to be closed (Institute of Transportation Engineers, 2006). This treatment consists in allowing a green signal to be given to road traffic near the level crossing just before the level crossing activation cycle starts. The benefits of such an approach are to reduce the queue at the crossing, as well as to reduce the likelihood of vehicles being trapped on the crossing when it is activated (Institute of Transportation Engineers, 2006).

This treatment was modelled through an extended green phase (0-30s each boom gate operation depending on the time of boom gate activation and the prevailing signal phasing) to flush as many vehicles as possible ahead of the boom gate closing.

Treatment 3: Reduce variability in warning times

One way to reduce level crossing congestion is to reduce the variability of warning times given to motorists (Sinclair Knight Merz, 2009). The variability of warning times is largely due to the requirements for a minimum warning to be met (based on maximum train speed), the technology used to activate level crossings (fixed strike-in points), the variability in train speeds (passenger/freight trains, stopping/express trains), and the approach of subsequent trains.

In this study, the reduction of variability in warning time is implemented by setting various permissible warning times for the activation of the boom gate event. Independent of the actual position, the strike-in event is triggered in a time window between 28 and 35 seconds. This means that the variability of actual warning time was limited to a 2-7 seconds window. In this implementation, stopping train recognition was also present to avoid the activation of the level crossing while the train was stopped at the adjacent station. It is acknowledged that the technical realisation of such a scenario is more complicated, but irrelevant at this stage of the research.

Treatment 4: Reduce minimum warning times

When comparing the minimum warning times required in Australia to similar settings in the US (Federal Highway Administration, 2019), the UK (Office of Rail Regulation, 2011), and New Zealand (New Zealand Transport Agency, 2012), it appears that the cycle in Queensland Australia, requiring 28 seconds warning before train arrival, is consistently longer, reaching an added 10 seconds when compared to the US. There seems to be space for reduction of the minimum warning time provided to road users while maintaining safety.

To simulate this scenario, the timings of sequences of train events have been changed to allow a minimum warning time of 18 seconds before train arrival. This lowered warning time by 10 seconds was achieved by removing 5 seconds of flashing lights and 5 seconds from the time to train arrival once the boom gates are closed.

Treatment 5: Reduce minimum road opening times

This treatment focuses on reducing the closure time due to consecutive trains approaching a level crossing. Once a train has cleared the level crossing, the activation cycle is not completed at that time if the approach of another train would result in the level crossing being opened for road traffic for less than 10 seconds. Ensuring that the minimum time available to road traffic provides a period long enough for meaningful traffic flow to occur, this approach could provide an effective way to reduce congestion at level crossings. Changing minimum open time values in the simulation can simulate this.

This approach is simulated in our study by reducing the minimum road opening time from 10 seconds to 5 seconds.

RESULTS

Level crossings' operation

The surveyed level crossings were characterised by road traffic ranging from 100 to 800 vehicles per hour, and by peak traffic ranging from 300 to 1,000 vehicles an hour. Most of the traffic consists of private cars (>85%), except for the Coopers Plains level crossing, which has a much higher proportion of commercial and heavy vehicles compared to the other level crossings.

During peak times, warning times are on average much longer than the minimum required, being over 60 seconds, about twice as long as required. There is also a large variability in these durations, ranging from 28 seconds (minimum required) to 350 seconds, and this is the result of variability in train speeds and the number of trains proceeding through during one level crossing closure. Warning time savings achievable for the average boom gate operation are on average 10-40s on the level crossings subject to investigation. Consequently, large queues of vehicles are present at level crossings during peak hours, ranging between 20 to 70 vehicles depending on the crossing considered. It has to be noted that the queue was not cleared by the opening of the level crossing, leading to vehicles waiting for multiple closures of the crossing to be able to go through the crossing.

Detailed results for each level crossing are presented in Table 1 and graphically represented in Figure 4.

TABLE 1 Level crossing areas and their rail and road operation

Level crossing site		Bonemill Road, Runcorn	Warrigal Road, Runcorn	Cavendish Road, Coorparoo	Boundary Road, Coopers Plains	Northgate Road, Northgate	Todds Road, Lawnton	Dawson Parade, Grovely
Traffic demand (veh/h)	Over a 24-hour period	100-200	400-600	400-600	600-800	200-300	200-300	400-600
	During peak periods	500	400-600	1000	800-1,000	800	300	800
Vehicle type	Private cars	85.5%	89%	89%	81.5%	87%	90%	89%
	Commercial vehicles	10.2%	7%	7%	10%	10%	6%	8%
	Trucks/buses	4.3%	4%	4%	8.5%	3%	4%	3%
Queue length (number vehicles)	Morning peak	70	32	30	66	40	24	44
	Afternoon peak	18	32	35	55	35	19	37
Observed trains (5 consecutive weekdays between 7-10am and 3-6pm)	All	498	498	273	498	600	600	350
	Express	293	293	96	206	91	522	50
Dwell time at adjacent station (s)	Inbound	31	37	43	38	63	32	43
	Outbound	33	33	36	36	72	41	36
Warning time (SD); min - max (s)	Inbound	62 (33); 28-157	74 (44); 28-350	39 (12); 27-103	62 (29); 29-125	45 (18); 28-123	102 (31); 38-157	54 (28); 29-204
	Outbound	58 (27); 28-127	63 (31); 28-145	65 (18); 28-127)	84 (38); 31-300	88 (31); 28-167	57 (26); 27-156	81 (20); 29-131
Possible warning time reduction (s)†	Inbound	34	46	11	32	17	74	26
	Outbound	30	35	37	54	60	29	53

†The minimum warning time required is 28s, except for Boundary Road and Coopers Plains, where it is 30s.

FIGURE 4 Overview of the level crossing areas and their rail and road operation

Simulations

First, the base model of each crossing was calibrated to replicate the survey data to a satisfactory level, followed by the simulation runs for the scenarios in the treatment list of the level crossing. The Bonemill Road and Warrigal Road crossings were simulated as a combined model, due to the proximity of these two level crossings. As no holistic observation was available for that combined model, the model has been calibrated individually for each crossing and then extended to the full scale. Simulations were run with a standard traffic composition, including normal cars only, and results were not separated into groups.

All models were successfully calibrated and provided travel time results in line with the observations conducted at the sites. Traffic simulations show that improvements to boom gate operations from all treatments would have a positive effect through a significant reduction of the travel time at the crossing and as a consequence a reduction in queues at the crossings. Among the tested scenarios, the biggest impact comes from reducing and possibly achieving the required warning times at level crossings, which are exceeded at the tested level crossings by 85% and more. The treatments which had the largest reduction in warning times were the ones with the most reduction in traffic delays (i.e. reductions in TT). Reducing variability in warning time can result in the warning time being divided by two for most of the crossings investigated. The reduction was much lower for three crossings, with a reduction of around 10%. These crossings are the combined Runcorn crossings, as well as the Coorparoo crossing.

Detailed results of the simulations for each treatment and each level crossing are presented in Table 2 and in Figure 5.

TABLE 2 Travel time as measured by the traffic simulation for the tested treatments

		Level crossing site						
Treatment	Outcome measure	Bonemill Road, Runcorn	Warrigal Road, Runcorn	Cavendish Road, Coorparoo	Boundary Road, Coopers Plains	Northgate Road, Northgate	Todds Road, Lawnton	Dawson Parade, Grovely
Base survey	TT (h)	N/A		131.0	325.8	35.5	38.8	78.4
	σ			1.8	49.9	1.2	2.2	2.2
Base model	TT (h)	542.6		127.7	318.5	33.6	36.4	75.3
	σ	46.3		2.1	20.7	0.6	1.3	1.0
Treatment 1: Restrict vehicle classes at the level crossing	TT (h)	N/A		N/A	287.4	N/A	N/A	N/A
	σ				1.6			
	Improvement (%)				9.8			
Treatment 2: Road signal pre-emption	TT (h)	542.6		114.4	222.0	N/A	N/A	N/A
	σ	46.3		1.8	11.0			
	Improvement (%)	0.0		10.4	30.3			
Treatment 3: Reduce variability in warning times	TT (h)	506.9		110.3	167.9	16.5	16.4	45.3
	σ	40.4		1.8	4.4	0.3	0.6	1.0
	Improvement (%)	6.6		13.6	47.3	50.9	54.9	39.8
Treatment 4: Challenge minimum warning times	TT (h)	505.3		106.7	162.6	15.0	15.5	42.4
	σ	25.6		1.5	4.7	0.3	0.6	1.0
	Improvement (%)	6.9		16.4	48.9	55.4	57.4	43.7
Treatment 5: Challenge minimum road opening times	TT (h)	537.4		119.5	272.3	24.0	26.9	60.7
	σ	37.7		2.3	20.5	0.7	0.8	2.1
	Improvement (%)	1.0		6.4	14.5	28.6	26.1	19.4

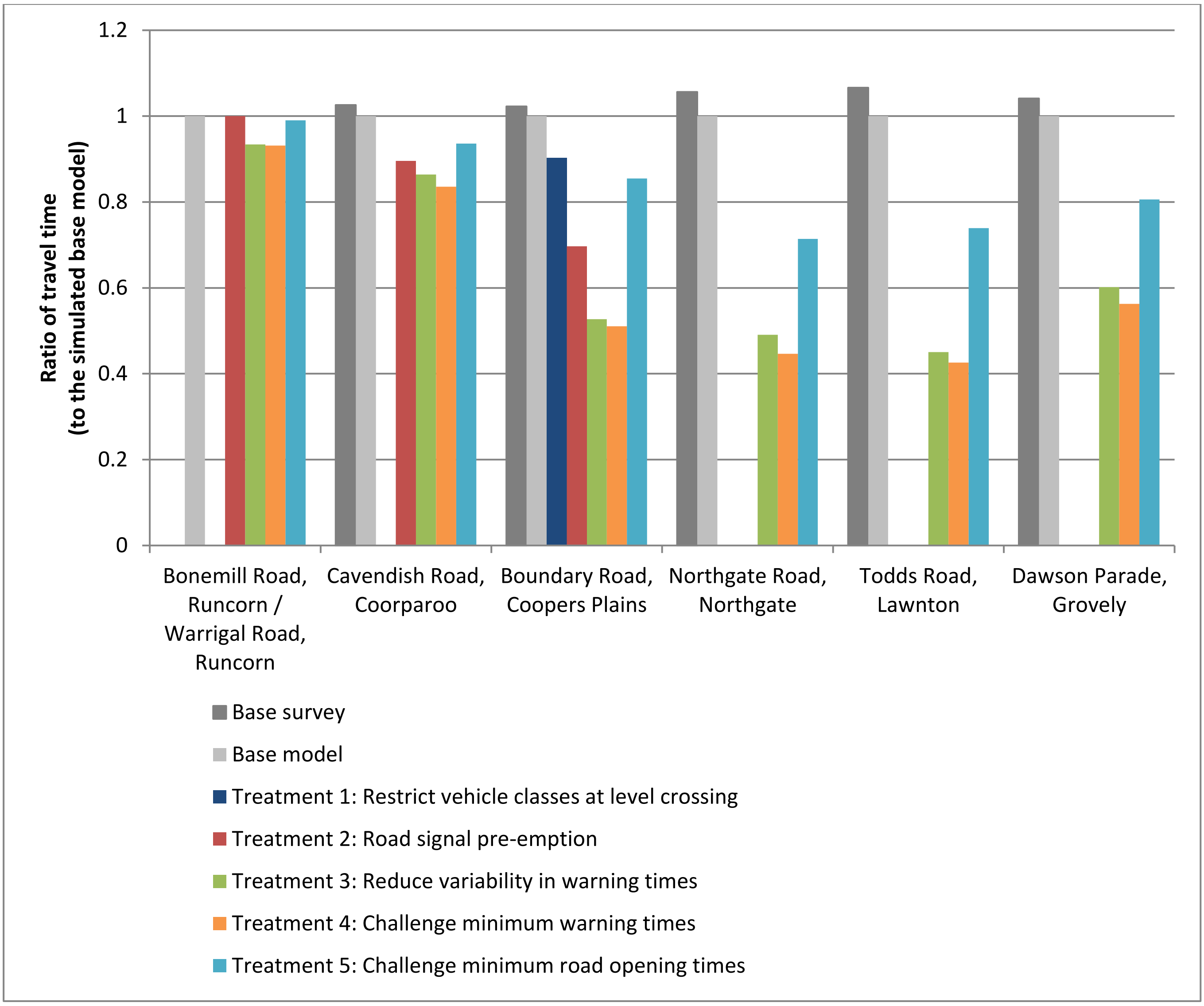


FIGURE 5 Effects of treatment on travel time

DISCUSSION

This study has shown that, given the technology used for activating level crossings, high train traffic can result in extended level crossing closures. The extended durations are largely due to warning times being longer than required for safety (double on average at the crossings considered in this study). This results in large queues at the level crossing. For road users, the time spent at level crossings can be much longer than the warning times reported here, as level crossings are often not re-opened long enough to clear the queue, and road users are likely to wait for multiple, very long, level crossing closures before being able to proceed through the crossing.

One cause for the additional warning times is the lack of identification of trains stopping at stations as they require a lowering of the boom gates even though the train is about to stop at the station. A simple adjustment of warning times for the trains stopping at a station was performed; however, when implementing such adjusted warning times, warning times remain 40% above the minimum required. This suggests that this factor is not the primary factor to focus on to reduce congestion significantly.

Based on the simulations, the highest priority for improvements is to achieve the warning time that is required due to safety regulations, rather than reduce minimum warning times (when safe to do so), regulate the types of vehicles at crossings, and pre-empt nearby traffic lights. If the variability in arrival times of trains at the level crossing can be reduced, closing times at the level crossing can be reduced and congestion levels can be improved significantly. The discrepancy between the actual speed of the trains, and the maximum speed, which is used to coordinate boom gate operation and train arrival to ensure the minimum warning times, is the primary factor leading to extended warning times at the level crossings observed in this study.

While regulating the types of vehicles allowed to use a crossing was shown to be effective in this simulation, this treatment might be difficult to implement. Implementing such a solution would necessitate the availability of appropriate alternative routes, and would require a case by case study to ensure that issues found at a given location are not transferred to another point in the network. It is also important to consider the impacts to the local community that such restrictions might induce.

Improvements with regards to the exceeding warning time could be achieved by reducing the line speed for level crossings where trains do not reach such speed. Speed reduction will have a positive effect if the reduction in posted speed is not affecting the rail line performance. The level of speed reduction that would not lower the performance is not determined within this study; however, line speed reduction could be implemented without affecting performance at some of the level crossings considered in this study. Indeed, the maximum train speed measured during the survey time was significantly lower than the line speed for some of the crossings. Implementation of a speed reduction would require adjustments to the rail network. Such adjustments include either moving strike in points or adding delays for the activation of the flashing lights (e.g. through a vital slow-release timer), making it a more complex task than changing speed on roads for instance. The current literature focused on long-term interventions based on Intelligent Transport Systems to improve awareness of crossing users and change their behaviour (I. Kim, Larue, Ferreira, Rakotonirainy, & Shaaban, 2015), but traffic simulations showed that such changes in driver behaviour may not always result in improved traffic performance at active level crossings. In contrast, our simulation results show that effective short-term treatments can be considered to reduce congestion at level crossings.

Some studies suggest that there is a significant increase in non-compliances when the time between train arrival and warning signal activation is greater than 20-30 seconds (Searle et al., 2012). Congestion at level crossings can also result in vehicles being stuck on the crossing (Coleman &

Moon, 1998; Larue, Naweed, et al., 2018). Naish and Blais (2014) and Larue et al. (2020) indicate that researchers have usually defined a long waiting period as between 3 and 5 minutes, although this may be culturally specific. Waiting periods at the investigated level crossings were often longer than these thresholds, and, therefore, each of the seven treatments considered for reducing road user delays might also positively affect safety at congested level crossings. These treatments could be an effective addition to enforcement, which requires an efficient deployment of limited resources (A. M. Kim, Wang, El-Basyouny, & Fu, 2016) and is therefore limited in practice at level crossings. However, no data on safety were assembled for this work, and further research should be conducted to confirm whether these treatments also reduce the number of vehicles stuck on crossings or non-complying with activated signals.

This study is the first to evaluate traffic improvement with short to medium-term treatments for congested level crossings. However, there are a number of limitations which need to be acknowledged when interpreting the results. First, the effects of the treatments were evaluated through traffic simulation. Field tests would be required to confirm that the findings hold in practice. However, traffic simulations were successfully calibrated with actual traffic from patterns from seven different congested level crossings, suggesting that the findings are likely to transfer to the field.

Further, this study has only been conducted on a small number of level crossings around Brisbane, Australia, and on one rail line. However, the fact that the issue of warning times longer than necessary occurs in many parts of the world (Abraham et al., 1998; Coleman & Moon, 1998; Larue, Naweed, et al., 2018; Level crossing removal authority, 2016; Naish & Blais, 2014), suggests that the findings from this study may be relevant to jurisdictions outside Australia. Further studies should nevertheless be conducted in order to confirm this, particularly since our traffic simulations also highlighted that each level crossing has its characteristics, and that there is no one fit all solution to reduce delays. This aligns with current research, which has highlighted that crossing safety models largely vary based on specificities such as geographical location in the US (Liu & Khattak, 2017) or in Europe (Liang & Ghazel, 2018).

Another limitation is that this study did not consider the cost involved in implementing such treatments or the timeline for such implementation. In practice, it would be therefore necessary to first understand the main factors leading to congestion at a given crossing, which can be done through a survey of the crossing or the analysis of the data logged by the level crossing system. Then, simulations would be necessary to ensure the selected approach is effective at that crossing. Potential negative effects on other parts of the network should also be investigated, through modelling a bigger part of the network as compared to what was done in this study.

It has also to be noted that the modelling used in this study did not take account of abnormal events or conditions, (e.g. broken down vehicle near the crossing, failed traffic light upstream) and therefore cannot conclude on the effectiveness of the treatments evaluated in such conditions. Rather, the study focused on the optimum use of the crossing to avoid congestion occurring daily rather than due to rare events which might occur in the real world.

However, this study has identified the areas of improvement that would have the greatest impact on reducing congestion at level crossings, and that some treatments can be implemented with high benefits in the short to medium-term. Rail companies should aim to review the variability of warning times at level crossings, and aim to reduce the variability of train speeds as much as possible given their network constraints. Such an approach could reduce congestion significantly before more advanced technology (Cho & Rilett, 2003) are implemented to activate level crossings while taking into account the train's actual train speed. This has therefore managerial implication for the rail operators, with the need to ensure that practice at level crossings aligns with the theoretical one used to design a safe level crossing. In particular, future work should investigate whether train timetables could be optimised to reduce delays at level crossings, and whether such optimisations and treatments would be resilient to variations around the planned train arrivals at the crossings.

CONCLUSION

This study has found that the variability of warning times (time that passes between the activation of the red lights until the train arrives at the level crossing) is a major cause of unnecessary level crossing closure: warning time savings achievable for the average boom gate operation are 10-40s on the level crossings subject to investigation. Traffic simulations have also shown that improvements are possible: if the variability in warning times can be reduced it is anticipated that travel time would lower significantly for road users. Travel time could be improved at all investigated level crossings by at least 7% and halved for four of these seven crossings.

A major cause for the variability in warning times are trains stopping at stations that are not equipped with express train identification, and the difference between posted line speeds and actual train speeds. Those factors prolong the warning time by 40% and more. As this variability also affects traffic light coordination, the benefits would add up.

The most effective way to reduce variability in warning times at the level crossing considered is to lower posted line speeds. This study has not evaluated the effect of such treatment on train operation. However, it is anticipated that improvements can be realised without requiring changes to the timetabling in cases where the speed of fastest trains speeds is significantly lower than the train line speed, offering the potential for short to medium-term treatment of congestion issues at level crossings.

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