Impacts of Rail-Road Crossings: International Synthesis and Research Gaps

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ABSTRACT
Rail-road crossings generate a range of transport, economic, social and environmental impacts. While much research has focused on selected impacts such as safety, little consideration has been given to wider impacts. The aim of this research was to therefore develop a holistic understanding of the impacts of rail-road crossings (both at-grade and grade-separated) and to identify key gaps in knowledge in this field. An international synthesis of rail-road crossing impacts was developed through a detailed literature review, which revealed a total of 18 different types of impacts associated with rail-road crossings. The review found that most research to date has focused on quantifying transport and economic impacts, particularly safety and road vehicle delay, with little consideration given to social and environmental impacts. A number of research gaps have been identified which provide a clear agenda for future research. These gaps include the use of empirical evidence to support impact assessments, and the need to better understand the impacts of grade separating rail-road crossings in terms of safety, travel time variability, rail vehicle delay, traffic flow, land use, crime, and disability access.

Word count: 182 words
INTRODUCTION

Rail-road crossings are a common feature of many transport networks, having increased in number with the expansion of rail and road systems in various countries. In the United States, there are now around 250,000 at-grade rail-road crossings, or one for every 0.6 km (0.4 mi) of rail line [1]. Australia has more than 23,000 at-grade rail-road crossings, or one for every 1.8 km (1.1 mi) of rail line, while New Zealand has more than 3,000 at-grade crossings, equivalent to one every 1.3 km (0.8 mi) of rail line [2].

Over the last 20-30 years, much research has been undertaken to investigate the impacts of rail-road crossings on road users. However, the majority of these studies have focused only on selected impacts (e.g. safety) with little consideration given to assessing the wider range of economic, social and environmental impacts.

The aim of the research is to develop a holistic understanding of the impacts of rail-road crossings and to identify key gaps in knowledge in this field. This paper considers both at-grade and grade-separated rail-road crossings. However, a particular emphasis is placed on the impacts associated with grade separation given its potential to alleviate many of the concerns associated with at-grade crossings, such as safety and traffic congestion [3-5]. The contributions of this paper include an international synthesis of rail-road crossing impacts and the identification of research gaps to provide a clear agenda for future research. This paper uses the term rail-road crossing to describe the location at which a railway line intersects with a roadway, regardless of whether this occurs at the same level (at-grade). Rail-road crossings are also commonly referred to as highway-rail crossings, highway-railroad crossings or level crossings (when at-grade).

In order to meet the research aim, a detailed literature review of academic research papers and industry reports relating to rail-road crossing impacts was undertaken. This included a synthesis of the literature to identify key themes and research gaps. The method used to source literature included searching for relevant papers in various databases including Scopus, ScienceDirect, Transportation Research Information Documentation (TRID), World Transit Research, Rail Knowledge Bank, and SPARK. A number of different search terms were used such as rail road crossing, highway rail crossing, level crossing, at-grade rail crossing, and rail grade separation. Contact was also made with relevant transport industry representatives to source additional literature. Following an initial scan of publications, a snowballing technique was adopted whereby additional literature was identified through the citations made in each publication [6]. Following a review of the title, abstract and reference list for each publication, a total of 70 publications were deemed to be relevant. However, only 28 of these focused specifically on the assessment of rail-road crossing impacts and therefore provided the main basis for the literature review. A number of the remaining 42 publications were used to provide context as needed.

This paper is structured as follows. The next section provides a detailed review of rail-road crossing impacts, including methods used for assessing them and their associated results. This is followed by a synthesis of rail-road crossing impacts to identify key themes that emerged from the literature. A discussion of key research gaps is then provided, followed by a set of concluding remarks.

DESCRIPTION AND ASSESSMENT OF RAIL-ROAD CROSSING IMPACTS

A total of 18 types of rail-road crossing impacts were identified in the literature, as shown in Table 1. This included eight different types of transport and economic impacts, seven types of social impacts and three types of environmental impacts. A description of each of these impacts is provided in the sub-sections that follow, including methods used for assessing them and their associated results.
TABLE 1 Types of Rail-Road Crossing Impacts$^a$ Identified by the Literature

<table>
<thead>
<tr>
<th>Transport &amp; Economic</th>
<th>Social</th>
<th>Environmental</th>
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<tbody>
<tr>
<td>• Safety (accidents)</td>
<td>• Land use (acquisition, value)</td>
<td>• Air quality (emissions)</td>
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<td>• Road vehicle delay</td>
<td>• Community cohesion</td>
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<td>• Rail vehicle delay</td>
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<td>• Vehicle operating costs</td>
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<td>• Traffic volume changes</td>
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<td>• Accessibility/connectivity</td>
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<td>• Crossing operation costs</td>
<td>• Sites of social significance</td>
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<td>• Grade separation costs</td>
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Source: Authors’ synthesis

$^a$ Includes impacts associated with both at-grade and grade-separated rail-road crossings

Transport and economic impacts

Safety (accidents)

Safety has arguably received the greatest attention of all rail-road crossing impacts in the research literature to date [7-14], with various studies investigating the role of emerging technologies in bringing about safety improvements [15-17]. Safety impacts are typically expressed by accident potential, both in terms of expected frequency and severity. Accidents at rail-road crossings can encompass all types of road users (e.g. cars, trucks, pedestrians, cyclists, public transport users) but can also include incidents with trains and damage to nearby property.

Safety impacts are usually estimated using existing (historical) data on accident rates and severity for specific locations [18-20]. Efforts have also been directed towards the development of accident prediction models for rail-road crossings, using key inputs such as traffic volumes and physical characteristics of the crossing [21, 22]. Other methods used to assess safety have included before and after video recordings to test the effectiveness of specific rail-road crossing safety measures [23-25]. Cost-benefit analyses have also been undertaken to assess the economic worth of level crossing safety measures [26]. As part of a cost-benefit analysis, Taylor and Crawford [27] assumed that all accidents at a rail-road crossing, plus 25% of accidents adjacent to it, would be saved if a site were to be grade-separated. In addition, both Corben et al. [28] and the Rail Safety & Standards Board [29] identify grade separation as a best practice measure for reducing crash risk. However, further empirical research in this area is needed to develop a better understanding of the accident reduction potential associated with the grade separation of rail-road crossings.

While the literature concerning the safety impacts of rail-road crossings has focused predominately on passenger car traffic, Taggart et al. [30] provides guidance for estimating accident potential at rail-road crossings for buses, carriers of hazardous materials (e.g. trucks), pedestrians and cyclists, based on the use of historical accident data. Other studies have investigated pedestrian safety at rail-road crossings [14, 25, 31, 32], with Freeman et al. [33] noting that males, school children and older pedestrians (and those with disabilities) are disproportionately represented in fatalities at rail-road crossings. While not directly related to rail-road crossings, Khatoon et al. [34] studied the behaviour of pedestrians using video recordings before and after the grade separation of a four-way signalised intersection in Delhi, India. They found that grade separation in the absence of pedestrian signals led to increased variability in vehicle speeds and risk taking behaviour by pedestrians.

Despite the strong focus on safety, estimation of accident costs have consistently shown to comprise only a small component of total costs associated with rail-road crossings. Through an assessment of 385 at-grade level crossings in Indiana, United States, Powell [18] found that non-accidents costs outweighed accident costs by a ratio of 3.5 to 1. Results of cost-benefit analyses of proposed rail-road grade separations have also told a similar story finding that savings from reduced level crossing crashes accounted for only 4-25% of total benefits [19, 20]. As noted by Dodgson [19]:

‘Where grade separations are under review other benefits, in particular those arising from reductions in highway vehicle delay, also become relevant and it is not satisfactory to concentrate only on accidents. Indeed the most effective solution to grade crossing accidents may be to secure as complete a protection with barriers as possible. Once this has been done the accident reduction benefits of grade separations may then be relatively small.’ [19]
Road vehicle delay

The impact of rail-road crossings on road vehicle delay has also received strong research attention to date [18, 35, 36]. Road vehicles such as cars and trucks can be delayed at rail-road crossings not only during times of train occurrences, but also at other times due to surface roughness of the crossing.

A number of research studies have developed generalised equations for estimating road vehicle delay at rail-road crossings, based mainly on traffic counts of vehicle arrivals and departures [18, 22, 37-39]. Microsimulation has also proved to be a popular tool for estimating road vehicle delay associated with rail-road crossings [18, 36, 37]. Okitsu et al. [40] developed a simulation-free method for calculating rail-road crossing delay by modifying Webster’s model of uniform delay to account for crossings that are pre-empted with connected traffic signals.

VicRoads [41] conducted travel time surveys before and after a rail-road crossing was grade-separated in Melbourne, Australia. Results showed that travel times generally decreased following the grade separation (up to 22% in peak periods). Travel time variability also decreased, yet a relatively small sample size limited the ability to any detect statistically significant differences. Further research in this area would therefore help to better understand the road vehicle delay impacts associated with rail-road grade separations.

Road vehicle delay has been shown to account for the majority of total costs associated with rail-road crossings. For example, through an assessment of grade separation schemes in Ontario, Canada, Dodgson [19] found that reductions in road vehicle delay accounted for the largest share of benefits at 72% to 94%. Here, vehicle delay included that from trains occupying the crossing as well as vehicles slowing down due to surface roughness.

Rail vehicle delay

In comparison to road vehicle delay, the impact of rail-road crossings on rail vehicle delay has received little research attention to date. Rail vehicles can be delayed due to permanent speed restrictions over crossings or any temporary speed restrictions that may be imposed following incidents. This in turn can result in additional rail operating costs associated with acceleration and deceleration [19], but also additional time costs for rail passengers.

Estimates of rail vehicle delay have typically been derived through the application of default unit costs [19] and values of time to affected rail passengers [42]. As part of a cost-benefit analysis of grade separation schemes in Australia, Taylor and Crawford [27] incorporated an economic cost of delay to train vehicles associated with accidents at rail-road crossings by applying a two-hour time delay per incident. In estimating rail vehicle delay associated with rail-road crossings, Taggart et al. [30] recommends the development of a detailed profile of existing (and planned) rail operations at the specific crossings under investigation.

Through the use of cost-benefit analysis, Dodgson [19] found that reductions in rail vehicle delay associated with rail-road grade separations accounted for only 0-6% of total benefits.

Vehicle operating costs

Rail-road crossings can impact vehicle operating costs through changes to fuel and oil consumption, tyre wear, vehicle maintenance and vehicle depreciation [18, 43]. Vehicle operating costs are usually estimated by applying default unit costs to vehicle traffic data specific to the crossings under investigation [18, 20]. Traffic data that is collected for this purpose typically includes vehicle volumes, vehicle mix, speeds and capacities [3]. As part of estimating vehicle operating costs associated with rail-road crossings, energy consumption, usually expressed in kWh, may be reported separately [18].

Traffic volume changes

Traffic volume changes can arise from physical changes implemented at rail-road crossings, such as grade separations, or from other factors that bring about changes in traffic flow to the surrounding area. While attempts have been made to explore these impacts, little is known about the extent to which traffic volumes can change following grade separation of a rail-road crossing.

Traffic modelling is typically used to estimate the extent of traffic diversion and reassignment arising from physical changes made to rail-road crossings [4, 30]. However, only one study to the authors’ knowledge has collected any empirical evidence of traffic volume changes. This study was
conducted by VicRoads [41] who collected traffic volume data at key locations before and after a rail-road crossing was grade-separated in Melbourne, Australia. Results showed that daily traffic volumes increased by 8% on the grade-separated road, with larger increases experienced in the AM peak (18% increase) and PM peak (15% increase). However, daily traffic volumes decreased on parallel (competing) roads by 6%, with larger decreases experienced in the peak periods (AM peak: 11-13% decrease; PM peak: 8-9% decrease). While this study provided evidence of traffic volume changes associated with the grade separation of a rail-road crossing, future research should look to determine the network-wide traffic impact (if any) of grade separation projects, while accounting for surrounding traffic growth during the evaluation period.

**Accessibility/connectivity**

Unlike other transport and economic impacts of rail-road crossings, accessibility/connectivity impacts have been considered mostly from a qualitative perspective to date. For example, Taylor and Crawford [27] subjectively assess the extent to which grade separation of a rail-road crossing would improve or worsen public transport access/use and connectivity of the surrounding road network. Delmonte and Tong [31] qualitatively assessed the problems that pedestrians with disabilities face at rail-road crossings, noting that these fall into three key categories: identification of the crossing, decision-making, and navigation and physical access. Moreover, McPherson and Daff [25] note that wheelchair users and other pedestrians with limited mobility can be particularly affected by rough surfaces and physical obstructions associated with at-grade rail-road crossings. In the context of grade-separated pedestrian crossing facilities, Cui et al. [44] highlights the potential for retail impacts at the street level due to the absence of direct pedestrian connections.

Schrader and Hoffpauer [39] developed an ‘accessibility factor’ to provide a simple quantitative measure of accessibility based on the difference in distance between a route using an at-grade crossing and a route using the nearest grade-separated crossing. In outlining methods to assess accessibility and connectivity associated with rail-road crossings, Taggart et al. [30] recommend mapping activity patterns in the area of interest and quantifying the extent to which travel times/distances are affected for different modes of transport.

**Crossing operation costs**

Costs associated with operating at-grade rail-road crossings can include items such as signage, protection equipment (e.g. automatic boom gates, flashing lights and bells) and surface maintenance [19, 30, 45]. Requirements for crossing attendant staff may also add to the cost of operating at-grade rail-road crossings [27]. In a cost-benefit analysis of grade separation schemes in Canada, Dodgson [19] found that reductions in crossing maintenance costs accounted for less than 5% of total benefits.

**Grade separation costs**

Costs associated with grade separation of a rail-road crossing typically include items such as design, construction, relocation of utilities, lighting, land acquisition, provision of traffic management and train replacement services during construction periods (plus any impacts to freight trains), and ongoing maintenance costs associated with bridges/subways [19, 30, 46].

Cost can vary considerably depending on local conditions, the extent of land acquisition required, and the type of grade separation solution adopted (e.g. lowering/raising the rail line is generally more expensive than lowering/raising the road). For example, Gitelman et al. [22] quotes an average construction cost of US$2.4 million per grade separation in Israel, while Washington State DOT [46] report costs ranging from US$29 million to an upper estimate of US$94 million per grade separation in the United States. In New Zealand, a number of options for grade separating a rail-road crossing are estimated at only NZ$2.5 million to NZ$10.9 million (approximately US$1.7 million to US$7.3 million).

Cost can also vary by construction approach. In Melbourne, Australia, a new ‘fast track’ approach has been adopted which speeds up construction to reduce construction impacts of rail/road users and local residents. This comes at a higher cost: a ‘fast track’ project in Middleborough Road in Melbourne was budgeted in 2005/06 at US$75 million but had only a 4 week construction period. This compared to a conventional ‘slow track’ construction time of 18 months and a likely budget of
between US$40-55 million [47]. Fast track construction has proven popular despite the high cost and is now the preferred approach to grade separation in Melbourne.

**Social impacts**

*Land use (acquisition, value)*

Various land use impacts can arise from rail-road crossings, particularly in the case of grade separations which often involve land acquisition. This in turn may change property values in the immediate surroundings as a result of changes to visual amenity, traffic levels and noise [48, 49].

Taggart et al. [30] recommend quantitatively assessing land use impacts by estimating the amount of land acquired by land use type and the number of structures displaced, in addition to assessing likely changes in property value, business activity, employment levels and development potential. City of Greater Dandenong [20] also adopt a quantitative approach through estimating urban consolidation benefits resulting from reduced land consumption at the urban fringe. While the land use impacts of rail-road crossings have received some research attention to date, there is a general lack of empirical evidence to support claims that are made, particularly in the context of grade-separated rail-road crossings.

**Community cohesion**

Schrader and Hoffpauer [39] define community cohesion as a sense of ‘oneness’ of a community. In contrast, Taylor and Crawford [27] use the term ‘community severance’ to describe the dividing effect that a road or railway can have on surrounding local communities, by forming a barrier to movement and social interaction.

At-grade rail-road crossings are generally perceived to contribute to a lack of community cohesiveness, while grade separations are seen as a potential solution to this issue [39, 49, 50]. For example, in advocating for the grade separation of a rail-road crossing in Melbourne, Australia, City of Greater Dandenong [20] argue that the grade separation can improve community connectedness, access to social infrastructure and encourage greater social interaction. However, Taylor and Crawford [27] note that community cohesion can be worsened in some cases of grade separations, particularly where overpasses are built which can result in the intrusion of an elevated structure and its approaches.

Schrader and Hoffpauer [39] provide a quantitative method for assessing community cohesion effects associated with rail-road crossings. This involves measuring the difference between the desire to travel from A to B and the desire to travel from B to A, with trips or attractions adopted as indicators of ‘desire’. The closer the difference in desire is to zero, the more cohesive the community is deemed to be. In contrast, other studies opt for a more qualitative approach for assessing community cohesion based on professional judgement [27, 42].

**Geographic distribution**

Geographic distribution is defined as the ‘spread’ of road-rail crossing points available across a specified area. In the context of proposed rail-road grade separations, Schrader and Hoffpauer [39] quantify geographic distribution impacts as the ratio of the number of grade-separated rail-road crossings per km (or mi) to the total number of rail-road crossings per km (or mi) in a particular area along a particular rail line.

In contrast, Taylor and Crawford [27] assess the ‘strategic fit’ of rail-road grade separations by considering how well the proposals align with road network operating objectives covering public transport, freight and general traffic. Washington State DOT [46] qualitatively assess geographic distribution impacts through the consideration of socioeconomic justice, particularly in terms of any anticipated impacts on low income populations.

**Noise (traffic, trains)**

Rail-road crossings can result in noise associated with general traffic (e.g. stop-start conditions, crossing roughness) and the sounding of train horns. Taggart et al. [30] provide guidance on
quantitatively assessing noise levels associated with rail-road crossings through the use of nomographs, which can be used to predict highway traffic noise under different conditions.

Other studies provide more of a qualitative assessment of noise associated with rail-road crossings [4, 27, 42, 46]. In the context of rail-road grade separations, Taylor and Crawford [27] assume that the worst noise impact is likely to be associated with a rail overpass (where noise from trains is likely to be spread over a wide area) while the greatest potential for noise reduction is with a rail underpass.

**Crime**

Only one study to the authors’ knowledge has considered the impact of rail-road crossings on crime [42]. Here, a qualitative assessment was undertaken of the extent to which CPTED (Crime Prevention Through Environmental Design) principles could be supported through the grade separation of a rail-road crossing in Auckland, New Zealand. CPTED principles generally consider aspects such as territoriality, surveillance (informal and formal), access control, image/maintenance, activity program support, and target hardening [51].

**Visual amenity**

Visual amenity impacts associated with rail-road crossings have been studied mostly in a qualitative manner to date. Taggart et al. [30] note that rail-road crossing improvements may affect aesthetics either positively or negatively. For example, removing a dilapidated structure from view will generally improve aesthetics while introducing a structure to an area where none previously existed could create or increase visual intrusion [30]. In the context of grade-separated pedestrian crossing facilities, Cui et al. [44] notes the potential for skywalks to block or cut across important vistas.

Taggart et al. [30] recommend applying a qualitative visual contrast rating to rail-road crossing improvement schemes, ranging from insignificant to high, based on expert judgement. In contrast, City of Greater Dandenong [20] quantitatively assess the visual amenity impact of a rail-road grade separation in Melbourne, Australia, by reference to a proxy which is the rent increment associated with a fully developed and vibrant activity centre.

**Sites of social significance**

Taggart et al. [30] note that various impacts associated with rail-road crossings, such as noise and vibration, air pollution and visual intrusion, may alter the integrity or essential character of sites of social significance, such as historic buildings, archaeological sites and other cultural resources. They recommend undertaking a qualitative assessment of the extent to which sites of such significance may be affected by rail-road crossings, in consultation with local specialists. Similarly, Taylor and Crawford [27] apply a qualitative assessment of the impacts on sites of social significance based on local knowledge and inspection of mapping and aerial photography. They recognise that sites of social significance could also include heritage listed signal boxes, churches and community centres.

**Environmental impacts**

**Air quality (emissions)**

Air quality impacts of rail-road crossings are generally expressed in terms of pollutant emissions from vehicles which can substantially increase during times of idling while a train is passing [3]. Examples of pollutants include carbon monoxide, carbon dioxide, hydrocarbons, volatile organic compounds (VOCs) and nitrogen oxide.

Powell [18] assessed the amount of excess pollutant emissions (in kg), namely carbon monoxide and hydrocarbons, arising from rail-road grade crossings in the United States. Pollutant emissions were estimated by applying default conversion rates to vehicle traffic data available for the rail-road crossings. Protopapas et al. [3] used an emissions model to convert emissions data into monetised terms using unit costs. Their analysis showed that the combined cost of emissions and wasted fuel comprised only 7% of total costs associated with rail-road crossings.
**Water quality**

Unlike air quality, water quality impacts associated with rail-road crossings have been assessed in mostly qualitative terms to date. Water quality can be affected by road surface runoff (incorporating traffic-generated fuels, lubricants and litter), as well as eroded soils and organic matter. This in turn can affect surface water flow and turbidity, aquifer recharge rates and capacity [30].

Taggart et al. [30] notes that while quantitative techniques for measuring water quality are well established, these are relatively complex and time consuming. Instead, they recommend using professional judgement to assess water quality, particularly since water related impacts are often negligible in comparison to other impacts associated with rail-road crossings. Taylor and Crawford [27] apply a similar approach by assessing the impact on natural watercourses using local knowledge.

**Sites of environmental significance**

Similar to sites of social significance, impacts on sites of environmental significance associated with rail-road crossings have been appraised in purely qualitative terms to date. Sites of environmental significance can include wildlife habitats, areas with established vegetation and other protected areas.

Taylor and Crawford [27] and Washington State DOT [46] both assess sites of environmental significance in the context of rail-road grade separations using local knowledge. Similarly, Taggart et al. [30] recommend the use of a qualitative rating which should be assigned in consultation with appropriate local officials.

**Assessment of multiple rail-road crossing impacts**

A number of studies have simultaneously assessed multiple impacts associated with rail-road crossings. Various techniques have been adopted including cost-benefit analysis [19, 20, 42], multi-criteria assessment [4, 27, 39], trade-off analysis [30, 46], and transport modelling [4, 18, 46].

Cost-benefit analysis involves monetising impacts as either costs or benefits and discounting these over a predefined evaluation period (e.g. 20 years). A benefit cost ratio is then calculated in which a ratio of more than one indicates that the proposal is expected to return a net economic benefit. Cost-benefit analyses have been undertaken for various rail-road grade separation schemes, with benefit-cost ratios ranging from 1.3 to 3.2 in Auckland, New Zealand [42], 1.9 in Melbourne, Australia [20], and 0.2 to 2.8 in Ontario, Canada [19].

However, cost-benefit analysis can be limited where impacts are not easily quantified, particularly those relating to social and environmental aspects. In these cases, multi-criteria assessment is often adopted which involves scoring each impact against its ability to meet a set of predefined criteria. Scores are typically weighted to reflect their perceived importance, although this can be process can be subjective so is normally undertaken in agreement with relevant stakeholders. Schrader and Hoffpauer [39] note that individual impacts should be weighted based on the priorities of the communities involved. Using multi-criteria assessment, they applied a weight of 50% to safety impacts, 30% to road vehicle delay, and 20% to a combination of accessibility, connectivity and geographical distribution impacts. In some cases, multi-criteria assessment has been combined with cost-benefit analysis to capture both quantitative and qualitative impacts [4]. For example, in assessing grade separation options for a rail-road crossing, Auckland Transport [42] recommended an option with a benefit-cost ratio of 1.8, despite another option having a ratio of 3.2, as the preferred option scored higher in terms of qualitative impacts.

Similar to multi-criteria assessment, trade-off analysis considers a range of impacts although tends not to employ a formal scoring and weighting process. Impacts may still be monetised where appropriate but with trade-offs made between key impacts (e.g. accident savings vs. delay avoided). In the context of rail-road crossings, Taggart et al. [30] notes that with trade-off analysis, the decision will be based on the judgement of those with appropriate responsibility and authority.

Various transport modelling techniques have also been used to assess multiple impacts associated with rail-road crossings. Microsimulation has been used extensively to study road vehicle delay at rail-road crossings [36, 37] as well as other impacts such as vehicle operating costs, air quality and safety [18]. Strategic transport modelling has also been used to understand various transport and economic impacts associated with rail-road crossings, although this is typically used in conjunction with microsimulation [4].
Summary of methods and results

Table 2 presents a summary of methods and results associated with rail-road crossing impact assessments. In many cases, results cannot be easily generalised as they depend heavily upon the local context. This is particularly relevant to social impacts such as crime and sites of social significance.

<table>
<thead>
<tr>
<th>Impact</th>
<th>Assessment Methods</th>
<th>Results</th>
</tr>
</thead>
</table>
| Transport & Economic Impacts  | • Analysis of historical accident data  
• Development and application of accident prediction models  
• Collection of before and after data | • Grade separation assumed to eliminate all accidents at crossing, plus 25% of accidents either side of it  
• Accidents comprise only small proportion of total costs (4-25%) associated with rail-road crossings  
• Grade separation in absence of pedestrian signals can lead to increased variability in vehicle speeds and pedestrian risk taking behaviour |
| Road vehicle delay            | • Development and application of generalised delay equations, based mainly on traffic count data  
• Microsimulation modelling  
• Before and after travel time surveys | • Travel times can decrease following grade separation (Melbourne: up to 22% in peak periods)  
• Grade separation can reduce travel time variability  
• Road vehicle delay accounts for majority of total costs (72-94%) associated with rail-road crossings |
| Rail vehicle delay            | • Application of unit costs and values of time to affected rail passengers  
• Development of detailed profile of existing (and planned) rail operations | • Reductions in rail vehicle delay account for only small proportion of total benefits (0-6%) associated with rail-road grade separations |
| Vehicle operating costs      | • Application of unit/default costs to vehicle traffic data | • At-grade rail-road crossings can increase vehicle operating costs due to stop-start conditions |
| Traffic volume changes       | • Traffic modelling approaches  
• Before and after traffic counts | | |
| Accessibility/ connectivity   | • Qualitative assessments based on professional judgement  
• Calculation of difference in distance between route using at-grade crossing and route using nearest grade-separated crossing  
• Mapping of activity patterns and quantification of travel times/distances | • At-grade rail-road crossings can affect accessibility and connectivity of the road network  
• Pedestrians with disabilities can experience a range of accessibility issues at rail-road crossings  
• No generalised results; can be affected positively or negatively depending on local context |
| Crossing operation costs     | • Monetisation of all relevant items, e.g. signage, protection equipment, surface maintenance, crossing attendant staff | • Reductions in crossing maintenance costs account for less than 5% of total benefits associated with rail-road grade separations |
| Grade separation costs       | • Monetisation of all relevant items, e.g. design, construction, utilities, lighting, land acquisition, traffic management train replacement, maintenance | • Cost can vary considerably depending on local conditions and extent of land acquisition required (e.g. US$1.7 million in New Zealand to US$94 million in United States, per grade separation) |
| Social Impacts               | | |
| Land use (acquisition, value)| • Estimation of land acquired and number of structures displaced  
• Assessment of changes in property value, business activity, employment levels and development potential | • Grade separations can lead to changes in property values in immediate surroundings as a result of changes to visual amenity, traffic levels and noise |
| Community cohesion           | • Calculation of difference between desire to travel from A to B and desire to travel from B to A  
• Qualitative assessment of extent to which barriers to local movement can be removed | • At-grade rail-road crossings perceived to contribute to lack of community cohesion, while grade separations seen as potential solution to this issue  
• Community cohesion can be worsened in some cases of grade separations, particularly where overpasses are built (intrusive structures) |
SYNTHESIS OF RAIL-ROAD CROSSING IMPACTS

Table 3 provides a synthesis of rail-road crossing impacts covered by the research literature, indicating where they have been assessed, and whether they were assessed quantitatively or qualitatively. There are four key observations to note from Table 3. Firstly, transport and economic impacts have generally been assessed in a quantitative manner, compared to social and environmental impacts which have been assessed predominately through qualitative means. There are of course exceptions to this, such as accessibility/connectivity, a transport and economic impact which has typically been assessed in a qualitative manner, and air quality (emissions), an environmental impact which has generally been quantified in most cases.

Secondly, safety (accidents) and road vehicle delay, both categorised as transport and economic impacts, were included in almost all of the studies reviewed (23 and 18 respectively, out of a total of 28 studies). This is in contrast to some of the social and environmental impacts, such as crime which was only included in one out of the 28 studies reviewed.
Thirdly, while no clear pattern emerged in terms of the types of impacts assessed in particular countries, the literature is dominated by studies undertaken in the United States. Most of the remaining studies were undertaken in Australia, Israel, United Kingdom and other parts of Europe.

Lastly, with the exception of Taggart et al. [30], studies undertaken in more recent years appear to have considered a wider range of impacts. Examples include Taylor and Crawford [27], Crawford [4] and Washington State DOT [46]. This wider scope is potentially due to considerable safety gains being achieved at rail-road crossings in recent years, thereby necessitating the assessment of other impacts when allocating funding and prioritising crossing upgrades.

**TABLE 3  Synthesis of Rail-Road Crossing Impacts**

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>Country</th>
<th>Transport &amp; Economic</th>
<th>Social</th>
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<td>India</td>
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</table>

Legend: ● Impact assessed quantitatively ○ Impact assessed qualitatively
Source: Authors’ synthesis of the literature based on citations within the table
*a* Includes impacts associated with both at-grade and grade-separated rail-road crossings
*b* Study focused on grade-separated pedestrian crossing facilities rather than grade-separated rail-road crossings
Figure 1 provides a conceptual representation of rail-road crossing impacts and uses the numerical totals included in Table 3 to show that transport and economic impacts were given the most attention in the literature, accounting for more than half (62%) of the impacts included within the studies that were undertaken. Social impacts accounted for around one-quarter (27%) of the impacts included, while environmental impacts accounted for only 11%. The circular arrows in Figure 1 represent linkages that exist between impacts, indicating that they are generally not independent of one another. For example, accessibility/connectivity is inextricably linked to community cohesion, while road vehicle delay can directly affect both air and water quality in the surrounding area.

**FIGURE 1 Conceptual representation of rail-road crossing impacts*.**

Source: Authors’ synthesis
Note: Percentages refer to the extent to which impacts were included within studies reported by the literature
* Includes impacts associated with both at-grade and grade-separated rail-road crossings

**DISCUSSION**

This research has identified a total of 18 different transport, economic, social and environmental impacts associated with rail-road crossings. While rail-road crossings can generate a range of impacts, most research attention to date has been directed towards the assessment of transport and economic impacts, with social and environmental aspects generally considered in qualitative terms only. This practice has limited the prominence of social and environmental considerations in impact assessments.
concerning rail-road crossings, particularly where quantitative techniques such as cost-benefit analysis are used. Future research should therefore look to establish a greater balance by assessing transport, economic, social and environmental impacts in a more comprehensive manner. Ultimately, this should be supported by empirical evidence through before and after measurements and therefore not limited to predictions made through modelling alone. This is particularly important in the context of grade separations which may perform particularly well on transport and economic indicators but may have negative social and environmental consequences, resulting in a poor outcome overall. However, the costs associated with collecting empirical evidence and the ability to generalise results to other rail-road crossings also needs to be considered.

The lack of comprehensive and balanced impact assessments supported by empirical evidence has been identified as a key research gap, along with others in Table 4, to guide future research in the field of rail-road crossings. Other key research gaps centre on the need to better understand the impacts of grade separating rail-road crossings, particularly in terms of safety, travel time variability, rail vehicle delay, traffic volume changes, land use, crime, and disability access.

An additional impact associated with rail-road crossings that was not identified by the literature is concerned with the ability for grade separations to facilitate an increase in rail service frequency. This benefit should therefore be explored in future research.

**TABLE 4  Summary of Research Gaps and Opportunities Related to Rail-Road Crossing Impacts**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Research Gaps</th>
<th>Research Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety (accidents)</td>
<td>There is limited empirical evidence of the accident reduction potential associated with the grade separation of rail-road crossings</td>
<td>Analyse available data on accident rates and types before and after the grade separation of rail-road crossings, while controlling for external influences</td>
</tr>
<tr>
<td>Road vehicle delay</td>
<td>There is a limited understanding of the impacts of rail-road crossing grade separations on travel time variability</td>
<td>Collect and analyse data on travel times (and traffic volumes) along relevant roads before and after the grade separation of rail-road crossings; undertake a microsimulation study to provide a more detailed assessment of changes in travel time variability</td>
</tr>
<tr>
<td>Rail vehicle delay</td>
<td>Little research has been undertaken to accurately quantify the impacts of rail-road crossings on rail vehicle delay</td>
<td>Assess the impacts of rail vehicle delay associated with permanent and temporary speed restrictions on rail operation costs and passenger travel time</td>
</tr>
<tr>
<td>Rail service frequency</td>
<td>No research has been undertaken to assess the impact of grade-separating rail-road crossings on the ability to increase rail service frequencies</td>
<td>Undertake transport modelling to assess the impact of rail-road grade separations on rail service frequencies; validate the findings where possible</td>
</tr>
<tr>
<td>Traffic volume changes</td>
<td>No empirical research has been undertaken to assess the network-wide impact on traffic volumes associated with the grade separation of rail-road crossings</td>
<td>Collect and analyse data on traffic volumes along relevant roads before and after the grade separation of rail-road crossings, while accounting for external factors that may affect traffic growth</td>
</tr>
<tr>
<td>Land use (acquisition, value)</td>
<td>There is a lack of empirical evidence of the land use impacts associated with the grade separation of rail-road crossings, such as changes in property values, business activity and employment levels</td>
<td>Conduct a detailed before and after evaluation of land use impacts at rail-road crossing sites that have been grade-separated, while controlling for external factors</td>
</tr>
<tr>
<td>Crime</td>
<td>Little research has explored the impacts of rail-road crossings on crime, particularly in cases of grade separations</td>
<td>Develop a quantitative assessment framework for scoring rail-road crossings against CPTED principles, apply this to a sample of sites and validate using before and after data on crime occurrences</td>
</tr>
<tr>
<td>Disability access</td>
<td>Limited quantitative research has been undertaken to assess the impacts of rail-road crossings on disability access</td>
<td>Undertake a comprehensive assessment of the impacts of rail-road crossings on disability access</td>
</tr>
<tr>
<td>Various</td>
<td>Many types of social and environmental impacts associated with rail-road crossings have not been quantified to date, thereby limiting their prominence in cost benefit analyses and other quantitative assessments</td>
<td>Develop new methods and tools for appropriately quantifying social and environmental impacts associated with rail-road crossings</td>
</tr>
</tbody>
</table>
No empirical evidence is available of the overall impact of grade-separating rail-road crossings that takes into account all relevant transport, economic, social and environmental impacts. Conduct of comprehensive before and after evaluation of transport, economic, social and environmental impacts at rail-road crossings sites that have been grade-separated, while controlling for external factors.

CONCLUSION

The aim of the research underlying this paper was to develop a holistic understanding of the impacts of rail-road crossings and to identify key gaps in knowledge in this field. An international synthesis of rail-road crossing impacts was provided which indicated a strong focus to date on the quantitative assessment of transport and economic impacts.

A total of ten key research gaps were identified which provide a clear agenda for future research in the field of rail-road crossings. The research gaps are diverse and offer much opportunity for advancing knowledge, particularly in terms of understanding the wider impacts of rail-road grade separations. Acting on these gaps will help to better inform decision making regarding the design and investment of both at-grade and grade-separated rail-road crossings in the future.

ACKNOWLEDGEMENTS

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FIGURE 1 Conceptual representation of rail-road crossing impacts.

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52. Horan, T., *Evaluating At-Grade Rail Crossing Safety along the Knowledge Corridor in Massachusetts*, in *Department of Civil and Environmental Engineering*. 2013, University of Massachusetts Amherst: United States.