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What factors influence risk at rail level crossings? A systematic review and synthesis of findings using systems thinking

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ABSTRACT

Collisions between road users (drivers, cyclists, motorcyclists, pedestrians) and trains at rail level crossings (RLXs) remain an intractable issue. This systematic review aimed to determine what is known regarding the factors influencing risk at RLXs, with a focus on understanding the causal relationships across the entire sociotechnical system. A systematic search identified 88 published studies. The studies were categorised according to the type of outcome measured or analysed: (1) rates and severity of crashes; (2) unsafe and non-compliant road user behaviours; and (3) road user risk perception, attitudes and beliefs. Most studies focused on unsafe and/or non-compliant road user behaviour. The factors identified within the studies as influencing risk at RLXs were classified using the Accident Mapping (AcciMap) technique, a systems analysis framework. AcciMap maps the factors that influence behaviour across six system levels ranging from Government to the operating environment. Most of the factors identified within the studies related to physical attributes of the crossing itself, its operation, and the behaviours and attributes of road users. Comparatively fewer systemic factors were identified (i.e. policy and budgeting). Few relationships between factors were identified, indicating that little consideration has been given interactions between factors (i.e. how crossing design influences end-user decision making). A research agenda is proposed based on systems thinking and the use of a ‘many model’ approach to understand and address risk at RLXs.

1. Introduction

Collisions between road users (i.e. drivers, cyclists, motorcyclists and pedestrians) and trains at rail level crossings (RLXs) are a safety concern in Australia (e.g. Office of the National Rail Safety Regulator, 2018) and worldwide (e.g. European Railway Agency, 2017; Office of Rail Regulation, 2018). In addition to the human and social costs, these events incur a significant economic cost in Australia of over AUD$116 million annually (Tooth and Balmford, 2010). Collisions, reflecting instances where a train makes impact with a road user or their vehicle, and near misses, which represent a narrowly avoided collision, also have detrimental impacts on the mental health and wellbeing of train drivers (Corina and Adriana, 2013; Clarner et al., 2015), emergency services officers and bystanders.

There is a large body of research literature on the topic of RLX safety, as described in previous reviews (e.g. De Gruyter and Currie, 2016; Read et al., 2013). Despite this, there are concerns that our understanding of the factors influencing safety and behaviour at RLXs is limited, given that previous reviews have not applied a fully systematic review process, or used a structured systems thinking approach to analyse the results. The current review aimed to examine and synthesise the current transportation safety literature to answer the question: What are the main factors influencing risk at RLXs? This question was addressed using a systems thinking lens, with a focus on understanding the causal relationships across the entire sociotechnical system and identifying gaps for future research.

1.1. Systems thinking and accident prevention

Systems thinking is a philosophy currently prevalent within safety science (Grant et al., 2018; Newnam et al., 2017; Salmon et al., 2020; Underwood and Waterson, 2014). Contemporary models of accident prevention are underpinned by the notion that safety and accidents emerge from interactions between multiple components across entire

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systems (e.g. Dekker, 2011; Hollnagel, 2012; Leveson, 2004; Rasmussen, 1997). Advocates of systems thinking argue that a complex system cannot be understood by breaking it apart and analysing its components in isolation from one another. Instead, systems thinking approaches take the overall system as the unit of analysis and consider how the components interact to produce emergent phenomena, such as accidents (Rasmussen, 1997; Ottino, 2003). In particular, this approach highlights the importance of avoiding looking 'down and in' when understanding why adverse events occur, and instead advocates looking 'up and out' at the broader factors driving system behaviour (Dekker, 2011). Understanding and addressing how systemic issues such as economic pressures, organisational decision making and cultural influences filter down through the system to create the conditions for accidents to occur provides an important leverage point for improving safety (Rasmussen, 1997).

Systems thinking approaches have previously been advocated in road transport (e.g. Hughes et al., 2016; Larsson et al., 2010; Salmon et al., 2012) and rail safety (e.g. Read et al., 2019; Naweed et al., 2019; Wilson, 2014). In addition, modelling approaches based in systems thinking have been applied to understand behaviour at RLXs (e.g. Salmon et al., 2016; Read et al., 2016; Salmon et al., 2018).

One commonly applied systems model of accident causation is Rasmussen's Risk Management Framework (Rasmussen, 1997) and the related Accident Mapping (AcciMap) technique (Svedung and Rasmussen, 2002). According to the Risk Management Framework (see Fig. 1), accidents are a consequence of the decisions and actions of actors across a sociotechnical system, from those proximal in space and in time to the accident (e.g. road users and train drivers) to those more distal in the causal chain (e.g. supervisors, managers and government policy makers). In the RLX safety context the model proposes that collisions at RLXs are caused by not only the decisions and actions of crossing users

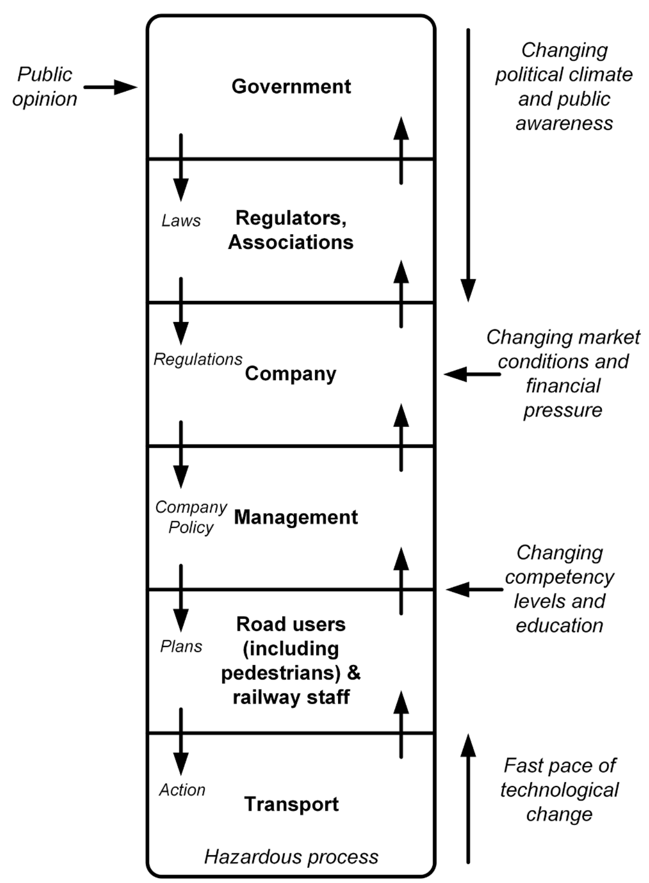

Fig. 1. Risk Management Framework for RLXs (adapted from Rasmussen, 1997).

(e.g. drivers, pedestrians) but also those of rail level crossing stakeholders such as rail companies (who make decisions regarding safety controls), safety regulators (who make decisions regarding inspections and enforcement) and governments (who allocate funding to safety initiatives).

Based on the Risk Management Framework, AcciMap has since been applied to understand accident causation in multiple safety–critical domains, ranging from public health and aerospace through to industry and transport safety to understand the network of factors influencing safety outcomes in a holistic and integrative manner (Hulme et al., 2019). AcciMap represents contributory factors across the hierarchical levels of a sociotechnical system. For example, Salmon et al. (2013) used AcciMap to describe the interacting network of contributory factors which played a role in the Kerang RLX collision in which 11 people were killed and 23 injured when a semi-trailer truck collided with a train at a RLX in Victoria, Australia in 2009. A conclusion from this and other work was that factors across RLX systems interact to influence risk at RLXs (Read et al., 2017; Salmon et al., 2013).

Accordingly, the AcciMap technique was used in this systematic review to understand the extent to which the literature has identified factors across the RLX system that influence road user safety and compliance at RLXs. The review concludes with a new research direction involving the requirement for a new application of a recently proposed 'many model' systems thinking approach to understand risk at RLXs.

2. Method

2.1. Protocol

The systematic review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The following information was extracted from each study: the type and year of publication; road user types studied (e.g. drivers, pedestrians, cyclists); the geographical context of study; research designs and data collection methods; and the factors, and interactions between factors found within the studies that influenced either the rate and severity of crashes, unsafe and non-compliant road user behaviours or road user risk perception, attitudes and beliefs.

2.2. Electronic search

The literature search was performed on seven databases (Table 1). Performing the search across the comprehensive range of databases allowed the systematic review to encompass both published journal articles (PsycINFO, Scopus, ScienceDirect, SAGE) and unpublished or "grey" literature indexed by the Transportation Research Information Database (TRID), the UK Rail Industry Safety and Standards Board's (RSSB) SPARK Rail Knowledge Hub, and the Australian Road Research Board's (ARRB) Knowledge Base repository.

The initial search was conducted between 29 and 31 May 2019, and included literature was published between the dates of 01 January 1980 to 31 May 2019, inclusive. Previous reviews have used similar search start dates (e.g. 1981 was used by Read et al., 2013). Citation software (Endnote X9) was used to facilitate the searching and screening process.

Based on the research question and scope of the research literature, Boolean search terms were generated, and limiters applied (Table 1).

2.3. Eligibility criteria

A set of inclusion and exclusion criteria were defined a priori to support the identification of studies relevant to the research question.

2.3.1. Inclusion criteria

Studies were included in the review where they met the following criteria:

Table 1
Keywords, limiters, and initial search results for each database searched.

Database	Search terms and limiters applied	Number of search results
PsycINFO	Title and Abstract: ("road user*" OR pedestrian* OR cyclist* OR motorcyclist* OR driver*) AND (unsafe OR complian* OR violat* OR risk*) AND (crossing*)) between 1980 and 2019	289
Scopus	TITLE-ABS-KEY((("road user*" OR pedestrian* OR cyclist* OR motorcyclist* OR driver*) AND (unsafe OR complian* OR violat* OR risk*) AND (crossing*)) AND PUBYEAR > 1979) AND (LIMIT-TO (LANGUAGE, "English"))	1,173
ScienceDirect	Title, abstract or author-specified keywords: (road user OR pedestrian OR cyclist OR motorcyclist OR driver) AND (risk OR unsafe OR compliance) AND (crossing)	337
SAGE	Abstract: ("road user*" OR pedestrian* OR cyclist* OR motorcyclist* OR driver*) AND (unsafe OR complian* OR violat* OR risk*) AND (crossing*)	184
TRID	TI(("road user*" OR pedestrian* OR cyclist* OR motorcyclist* OR driver*) AND (crossing*)) AND KEY(unsafe OR complian* OR violat* OR risk*)	372
SPARK	("road user" OR "road users" OR pedestrian OR cyclist OR motorcyclist OR driver) AND (unsafe OR compliant OR compliance OR violate OR violation OR risk) AND (crossing)	129
ARRB Knowledge Base	Reports, Conference and Journal– ("road user*" OR pedestrian* OR cyclist* OR motorcyclist* OR driver*) AND (unsafe OR complian* OR violat* OR risk*) AND (crossing*) between 01 January 1980 to 31 May 2019	874

i. The study sample involved traditional road users (i.e. drivers, cyclists, motorcyclists and/or pedestrians) and/or professional drivers (e.g. bus drivers, truck drivers, heavy vehicle drivers).
ii. The study focused on, and/or discussed factors and determinants of road user behaviour relating to risk. Factors and determinants included those relating to demographic, psychological, environmental, sociocultural, organisational, regulatory, and legislative considerations.
iii. The study evaluated behaviours on RLXs on the public road network, specifically, locations that require a stop, wait, and go decision.
iv. The study outcomes included behaviours relating to risk (i.e. non-compliances, near misses, crashes, injuries).
v. The study design was observational, epidemiological, or experimental. This included both qualitative and quantitative studies and data collection methods (e.g. interviews, focus groups, surveys/questionnaires, naturalistic/semi-naturalistic studies, simulations/modelling, and accident analyses).
vi. The study was published in the English language between 01 January 1980 and 31 May 2019, inclusive.

2.3.2. Exclusion criteria

Studies were excluded from the review where they met the following criteria:

i. The study sample involved only drivers of emergency response vehicles, trains, or other locomotives (e.g. line transportation), and rail maintenance and operational personnel.
ii. The study described road user cognition or behaviour at RLXs, but the study outcomes were not explicitly focused on behaviours relating to risk (i.e. non-compliances, near misses, crashes, injuries).
iii. The study only analysed the frequency of incidents at RLXs (e.g. collisions, trauma, fatalities), with no exploration of the factors influencing or contributing to collisions.
iv. The study focused on behaviours unrelated to the stop, wait, and go decision (e.g. compliance with speed restrictions).
v. The study focused on behaviours associated with suicide or trespass at RLXs.
vi. The study evaluated behaviours on road networks that do not involve RLXs. For example, signalised or unsignalised pedestrian crossings, pelican crossings, midblock junctions, light rail/tram intersections.
vii. The study was a review or synthesis of primary studies, a commentary, or provided anecdotal insights only.
viii. The publication was a book, thesis or a conference abstract.

Following the initial search, inspection of the titles and abstracts (where available) of all retrieved sources was performed by the second author against the eligibility criteria. In cases of insufficient details reported in the abstract and full-text and/or eligibility disagreements, discussions were held amongst the first three authors to gain consensus.

2.4. Data presentation and analysis

Each study was reviewed and the relevant information extracted.

Publication information extracted included year of publication, publication type, geographical context of the study, and the road user types studied.

Research design and analysis information extracted included sample size, research design, data collection methods and analytical methods used in each study.

Factors influencing risk at RLXs were extracted from each study where they were stated by the authors of the publication to be an influence on the outcome of interest based on analysis of study data. Three different types of outcomes of interest studied across the publications were identified: (1) Rates and severity of crashes/injuries; (2) Unsafe and non-compliant road user behaviours; and (3) Road user risk perception, attitudes and beliefs. The AcciMap technique was subsequently used to aggregate the influencing factors identified across studies and understand where they reside across the RLX system. For example, a study involving the development of a statistical model based on crash data reported train speed as having a significant relationship with injury severity (Liu and Khattak, 2017). Therefore, the factor 'train speed' was identified for inclusion in the analysis and was placed at the *equipment and surroundings* level of the AcciMap. A separate AcciMap was created for each of the three outcomes of interest described above.

Beyond representing factors at different system levels, the AcciMap technique enables the presentation of relationships identified between the influencing factors. Relationships were extracted from the studies where one factor was stated by the authors of the publication to have an effect on another factor, based on the analysis data. For example, one study found that the presence of other road users influenced decision making at RLXs, whereby participants were less likely to cross in front of a train where other road users were present (Beanland et al., 2016). Therefore, a relationship was documented between the influencing factors of *presence of other road users* and *decision making.*

3. Results

3.1. Full-text selection

The search across the seven databases yielded a total of 3,358 records. Following removal of 740 duplicates, the titles and abstracts of 2,618 records were examined. A total of 176 records were identified as potentially eligible for inclusion with a further six records identified through bibliographic screening. Based on full-text screening, 94 records were excluded for several reasons, as listed in Fig. 2. Taken together, this

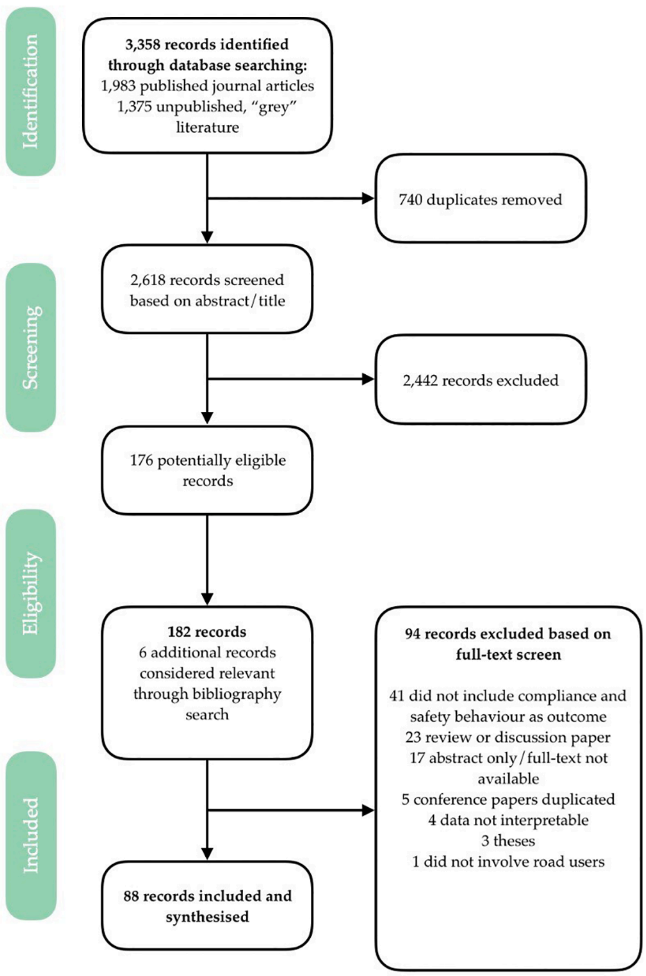

Fig. 2. Systematic review process and outcomes.

process resulted in the inclusion and synthesis of a total of 88 records.

3.2. Publication information

The 88 studies were published between the years of 1989 to 2019. The highest number of studies ($n = 10$) were published in 2015.

3.2.1. Publication type

The majority of studies were published as peer-reviewed journal articles ($n = 58$) or conference papers ($n = 16$). Thirteen were technical reports and two were book chapters published as part of a series of published lecture notes.

3.2.2. Geographical context

The largest proportion of studies were conducted and/or based on RLXs operating within Australia ($n = 36$; 41%) and North America or Canada ($n = 35$; 40%). Thirteen studies (15%) were conducted in Europe (including the United Kingdom), and two studies (2%) were conducted in Asia (i.e. Japan and Indonesia).

3.2.3. Road user types studied

As illustrated in Fig. 3, most studies ($n = 58$; 66%) focused exclusively on drivers. A smaller group of studies investigated pedestrians only ($n = 16$; 18%), or more than one category of road users (e.g. cyclists and pedestrians, or pedestrians and drivers; $n = 11$; 13%). Four of the included studies (5%) did not specify the type of road user studied. Three of these were based on existing accident and crash databases and did not specify the road users involved in the crashes, and the other (i.e., Cercarelli and Guilfoyle, 2005) sampled stakeholders and community members on their perceptions of road safety. An inspection of the road user types studied over time revealed that as a group, drivers are consistently overrepresented. However, the number of studies focusing on pedestrian behaviour is increasing, as well as studies incorporating more than one category of user.

3.3. Research design and analyses

Information regarding sample size, research design, data collection methods and analytical methods of the included studies is presented in Table 2. A more detailed and comprehensive extraction table which features the outcome(s) measured and the factors found to influence outcome(s) in each of the studies, is provided as supplementary material.

In relation to research design, most studies were descriptive ($n = 36$; 41%). Such designs aim to describe the current state of affairs rather than determining associative or causal effects. The remaining studies were experimental ($n = 14$; 16%), quasi-experimental ($n = 19$; 22%), mixed methods ($n = 11$, 13%) or epidemiological ($n = 10$; 11%).

In relation to participants and their characteristics (where reported), the sample sizes in the studies ranged vastly, from one (e.g. Salmon et al., 2013) to over five hundred thousand (Liang et al., 2017). The gender distribution of participants was not consistently reported. Many studies that did not report gender were descriptive or involved

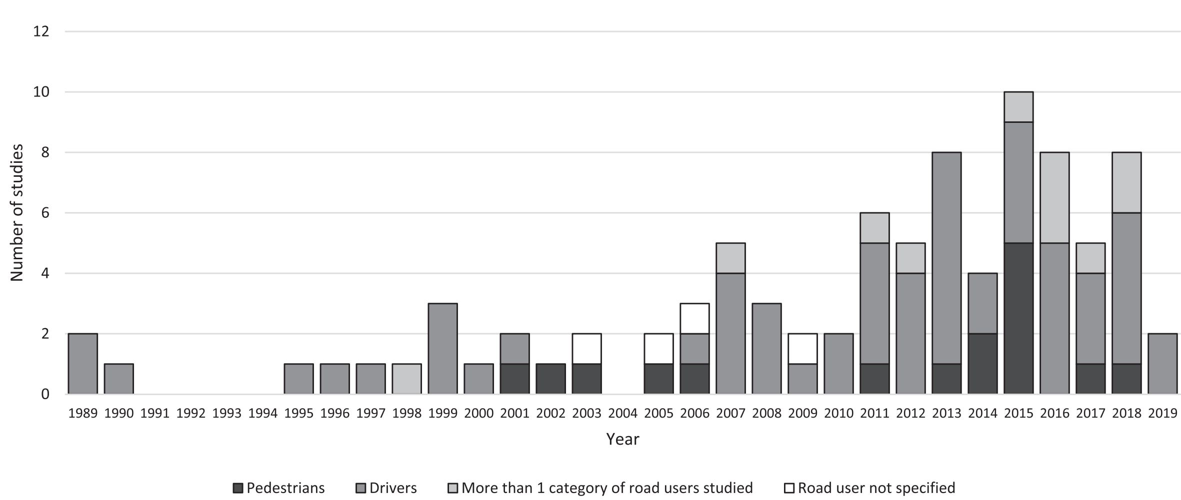

Fig. 3. Stacked histogram depicting road user group types studied across years 1989 to 2019, inclusive.

Table 2
Overview of extracted information – author name(s), publication year, sample size, research design, method of data collection and analytical method of studies included in the review.

Author(s), Publication Year	Sample Size	Research Design	Data Collection Method	Analytical Method
Abdel-Rahim et al. (2015)	265	Quasi-Experimental, Descriptive, Epidemiological	Existing accident and crash database, self-report questionnaire	Empirical Bayes method, Wilcoxon Signed Rank tests
Anandarao and Martland (1998)	–	Epidemiological	Existing accident and crash database	Probabilistic Risk Assessment
Atkins Rail (2007)	–	Quasi-Experimental	Video-based observation	Chi-Square tests
Barić et al. (2018)	8,259	Descriptive	In-situ observation, video-based observation, self-report questionnaire	Count
Baron and da Silva (2019)	–	Quasi-Experimental	Video-based observation	Count
Beanland et al. (2018)	30	Experimental	Driving performance measure (simulator), verbal response, self-report questionnaire	Regression analyses, Chi-Square tests, ANOVA
Beanland et al. (2016)	166	Descriptive	Self-report daily diary entries	Regression analyses
Beanland et al. (2017)	22	Quasi-Experimental	Driving performance measure (simulator), Critical Decision Method interview	Regression analyses, T-tests
Beard (2003)	–	Descriptive, Epidemiological	Existing accident and crash database, observation (not specified)	Count
Carlson and Fitzpatrick (1999)	1,008	Descriptive	Video-based observation	Regression analyses
Cercarelli and Guilfoyle (2005)	100	Descriptive	Self-report questionnaire	Count, Thematic analyses
Chase et al. (2013)	–	Quasi-Experimental	Video-based observation	Chi-Square tests
Coleman and Venkataraman (2001)	272	Quasi-Experimental	Video-based observation	Count
Darvell et al. (2015)	119	Descriptive	Self-report questionnaire	Correlational analyses
Davey et al. (2006)	51	Descriptive	Self-report questionnaire, semi-structured interview	Thematic analyses
Davey et al. (2007)	69	Descriptive	Self-report questionnaire	T-tests
Davey et al. (2008a)	43	Descriptive	Semi-structured focus group	Thematic analyses
Davey et al. (2008b)	53	Descriptive	In-situ observation	Count
Edquist et al. (2011)	52	Descriptive	In-situ observation	Count
Freeman et al. (2015)	44	Descriptive	Focus group	Thematic analyses
Freeman and Rakotonirainy (2015)	636	Descriptive	Self-report questionnaire	Regression analyses
Freeman and Rakotonirainy (2017)	636	Descriptive	Self-report questionnaire	Regression analyses
Gabree and da Silva (2014)	438	Quasi-Experimental	Video-based observation	Chi-Square tests
Gabree et al. (2014)	12,989	Quasi-Experimental	Video-based observation	Chi-Square tests
Grippenkoven et al. (2012)	51	Epidemiological	Existing accident and crash database	Chi-Square tests
Haleem (2016)	1,117	Epidemiological	Existing accident and crash database	Regression analyses
Hao et al. (2015)	25,945	Epidemiological	Existing accident and crash database	Regression analyses, Likelihood Ratio tests
Heathington et al.(1989)	–	Quasi-Experimental	Video-based observation	Chi-Square tests
Hughes et al. (1999)	1,266	Descriptive, Epidemiological	Driver history database, photo-based observation, self-report questionnaire	Chi-Square tests
Huntley-Fenner (2006)	60	Descriptive	Video-based observation	Count
Kasalica et al. (2012)	61	Descriptive	Video-based observation	ANOVA, Regression analyses
Khattak (2007)	3,283	Quasi-Experimental	Video-based observation	T-tests, Regression analyses
Khattak (2009)	6,205	Quasi-Experimental	Video-based observation	Regression analyses
Khattak (2013)	476	Descriptive	Video-based observation	Regression analyses
Khattak (2014)	582	Quasi-Experimental	Video-based observation	Regression analyses
Khattak et al. (2012)	–	Quasi-Experimental	Video-based observation	Regression analyses
Khattak and Luo (2011)	–	Quasi-Experimental	Video-based observation	Regression analyses, T-tests
Khattak and Zhao (2016)	915	Descriptive	Self-report questionnaire	Regression analyses
Kim et al. (2013)	30	Experimental	Driving performance measure (simulator)	Count, Wilcoxon tests
Ko et al. (2007)	3,440	Quasi-Experimental	Video-based observation	Chi-Square tests, T-tests
Laapotti (2016)	5,408	Epidemiological	Existing accident and crash database	Chi-Square tests
Landry et al. (2018)	17	Experimental	Driving performance measure (simulator)	ANOVA, Regression analyses
Larue and Wullems (2015)	15	Experimental, Descriptive	Driving performance measure (simulator), self-report questionnaire	Generalised linear mixed modelling
Larue et al. (2018a)	60	Experimental	Driving performance measure (simulator)	Generalised linear mixed modelling
Larue et al. (2015)	58	Experimental	Driving performance measure (simulator)	Generalised linear mixed modelling
Larue et al. (2018b)	712	Descriptive	In-situ observation	Count
Larue et al. (2016)	20	Experimental	Driving performance measure (simulator)	Generalised linear mixed modelling
Lenné et al. (2011)	24	Experimental	Driving performance measure (simulator)	ANOVA, T-tests, Chi-Square tests
Liang et al. (2017)	506,834	Descriptive	Observation (via digital counter)	Count
Liang et al. (2018)	461,596	Descriptive	Observation (via digital counter)	Count
Liu et al. (2016)	64	Experimental	Driving performance measure (simulator)	Regression analyses, Path analysis
Liu and Khattak (2017)	7,129	Epidemiological	Existing accident or crash database	Path analysis, Geo-spatial modelling techniques
Liu and Khattak (2018)	7,129	Epidemiological	Existing accident or crash database	Path analysis, Geo-spatial modelling techniques
Lobb et al. (2001)	394	Experimental, Descriptive	In-situ observation, self-report questionnaire	Chi-Square tests, T-tests, Correlational analyses

(continued on next page)

Table 2 (*continued*)

Author(s), Publication Year	Sample Size	Research Design	Data Collection Method	Analytical Method
Lobb et al. (2003)	172	Experimental	In-situ-observation, self-report questionnaire	MANOVA, Correlational analyses
Lorio et al. (2012)	–	Descriptive	Case study, self-report questionnaire	Count
McKenzie-Kerr (2011)	–	Quasi-Experimental, Descriptive	Video-based observation	Count
McMaster et al. (2014)	703	Descriptive	Focus groups, self-report questionnaire, interview	Thematic analyses, Regression analyses, Correlational analyses
McPherson and Daff (2005)	–	Epidemiological, Descriptive	Existing accident or crash database, interview, questionnaire	Count
Meeker and Barr (1989)	57	Descriptive	In-situ observation	Chi-Square tests
Meeker et al. (1997)	60	Descriptive	Video-based observation	Chi-Square tests
Millegan et al. (2009)	–	Epidemiological	Existing accident or crash database	Regression analyses
Mulvihill et al. (2016)	352	Descriptive	Self-report questionnaire, daily diary entries	Count
Naweed et al. (2016)	757	Descriptive	In-situ observation, self-report questionnaire, interview	Thematic analyses
Palat et al. (2017)	304	Descriptive	Self-report questionnaire	Correlational analyses, Regression analyses
Raub (2006)	42,219	Epidemiological	Existing accident or crash database	Wilcoxon tests, ANOVA
Richards and Heathington (1990)	3,500	Descriptive, Quasi-Experimental	Video-based observation, laboratory study	Count
Rudin-Brown et al. (2010)	25	Experimental	Driving performance measure (simulator)	Chi-Square tests
Rudin-Brown et al. (2012)	25	Experimental	Driving performance measure (simulator)	ANOVA, T-tests, Chi-Square tests
Russell et al. (2007)	4,318	Descriptive	Video-based observation	Pooled estimate of population variance
Salmon et al. (2013)	1	Descriptive	Case study	
Siques (2002)	7,703	Quasi-Experimental	Observation (type not specified)	T-tests
Stefanova et al. (2015a)	–	Descriptive	In-situ observation	Chi-Square tests, ANOVA, Relative Deviations, Correlational analyses
Stefanova et al. (2015b)	12	Descriptive	Focus group	Thematic analyses
Stefanova et al. (2018)	222	Descriptive	Self-report questionnaire	Chi-Square tests, Fisher's Exact tests, ANOVA, Regression analyses
Taylor (2008)	4,400	Descriptive	Focus group, in-depth interview, self-report questionnaire	
Tey and Ferreira (2010)	368	Quasi-Experimental	Video-based observation	Chi-Square tests
Tey et al. (2011a)	24	Experimental, Descriptive	Driving performance measure (simulator), video-based observation	Chi-Square tests
Tey et al. (2013a)	24	Experimental	Driving performance measure (simulator)	Regression analyses
Tey et al. (2013b)	24	Experimental	Driving performance measure (simulator)	Chi-Square tests, ANOVA
Tey et al. (2011b)	24	Experimental	Driving performance measure (simulator)	Chi-Square tests
Tjahjono et al. (2019)	154	Epidemiological	Existing accident or crash database	Regression analyses
Ward and Wilde (1995)	–	Quasi-Experimental	In-situ observation	ANOVA
Ward and Wilde (1996)	–	Quasi-Experimental	In-situ observation	ANOVA
Witte and Donohue (2000)	891	Descriptive	Self-report questionnaire	T-tests, Path analysis
Yeh et al. (2013)	–	Epidemiological	Existing accident or crash database	ANOVA
Zeilstra et al. (2015)	–	Descriptive	Video-based observation, Track-based signalling	ANOVA
Zwahlen and Schnell (1999)	–	Quasi-Experimental, Descriptive	Video-based observation, self-report questionnaire, existing accident or crash database	Chi-Square tests

naturalistic observation of unspecified road users. In studies that reported the gender distribution of their sample, males were over-represented (e.g. Darvell et al., 2015; Davey et al., 2006; Larue and Wullems, 2015; Lenné et al., 2011).

A range of data collection methods were used across the studies. More commonly used data collection methods were *in-situ* (i.e. on-site and in real-time) or video-based observation, self-report questionnaires, and driving performance measures obtained from driving simulator studies. Other forms of data collection methods included focus group and daily diary entries. For epidemiological studies, existing accident or crash data were used to infer behaviours related to risk.

The adopted analytical methods varied. Many descriptive studies reported counts of behaviours ($n = 16$; 18%) or the outcomes of thematic analyses (i.e. of interview or focus group transcripts; $n = 8$, 9%). Others used statistical tests such as chi square ($n = 23$; 26%), correlational analyses ($n = 6$; 2%), t-tests ($n = 10$; 11%), ANOVAs ($n = 13$; 15%) and regression analyses ($n = 24$; 27%).

3.4. Overview of influencing factors

Several factors deemed to influence risk at RLXs were identified across the 88 studies. The full extraction table in the supplementary material shows the factors identified from each included study.

In order to clarify the relationships between factors and outcome variables, separate AcciMaps are presented for three outcomes of interest: (1) Rates and severity of crashes/injuries; (2) Unsafe and non-compliant road user behaviours; and (3) Road user risk perception, attitudes and beliefs. It should be noted that the total number of papers described across the three AcciMaps do not sum to 88. This is because a small number of papers ($n = 7$; Abdel-Rahim et al., 2015; Davey et al., 2008a; Khattak and Zhao, 2016; Liu and Khattak, 2017; Liu and Khattak, 2018; Lobb et al., 2003; Zwahlen and Schnell, 1999), assessed two or more outcomes. For example, Liu and Khattak (2017) analysed data contained within an accident/crash database relating to both rates and severity of crashes/injuries (outcome 1) and to unsafe and non-compliant road user behaviours (outcome 2). The factors they identified from their analysis which influenced each of these outcomes were documented separately in relation to each particular outcome and included in the relevant AcciMaps.

3.4.1. Factors influencing rates and severity of crashes

Eighteen studies assessed factors influencing the rate and severity of crashes at RLXs. Thirteen studies (72%) were epidemiological or mixed methods with an epidemiological component, investigating causes and influencing factors to crashes over several years (e.g. crashes between road users and trains at private RLXs over a six-year period in the USA; Haleem, 2016). The factors identified as influencing rates and severity of crashes are shown in Fig. 4. Relationships between factors that were

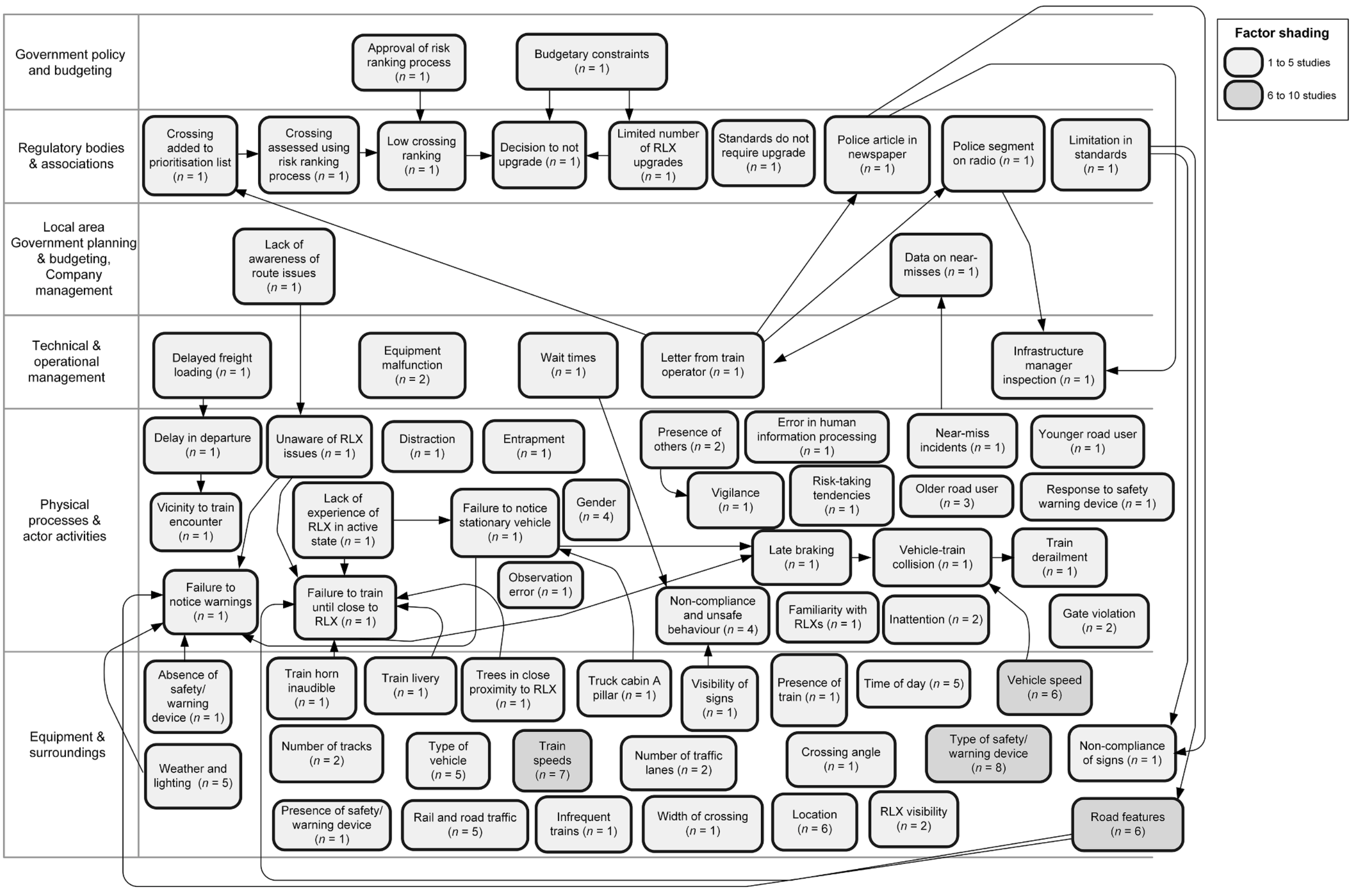

Fig. 4. AcciMap of factors influencing rates and severity of crashes ($n = 18$). Note, each relationship between two factors shown with arrows were identified within only one study.

reported within the studies are shown by arrows linking the factors.

Most of the influencing factors identified were classified within the lower two system levels: *physical processes and actor activities* (26; 35%); and *equipment and surroundings* (24; 38%). While some factors were identified at the higher levels of the AcciMap, the majority were reported in a single study, itself constituting an AcciMap analysis of the Kerang RLX crash occurring in Victoria in 2007 (Salmon et al., 2013).

The four factors identified most frequently across the studies (i.e. the type of safety/warning device in place, train speeds, road features and road vehicle speeds), all resided within the *equipment and surroundings* level.

3.4.2. *Factors influencing unsafe and non-compliant road user behaviours*

Sixty-seven studies assessed unsafe and non-compliant road user behaviours. The factors identified in the studies as influencing these behaviours are shown in Fig. 5. It can be seen that the most frequently identified factors influencing non-compliance and unsafe road user behaviours resided within the *physical processes and actor activities* level ($n = 34$; 49%), followed by the *equipment and surroundings level* ($n = 23$, 33%).

Within the *physical processes and actor activities* level, the most frequently identified factors were gender, younger road users, the presence of others at the crossing, time pressure, familiarity with the crossing, the type of road user, having low perceptions of risk, and having an intention to violate.

Within the *equipment and surroundings* level, the most frequently identified factors were the type of safety/warning device provided at the crossing, the presence of trains, frequency of road and rail traffic, the location of the RLX, weather and lighting conditions, and the time of day.

Few factors were identified at the top four levels of the AcciMap.

3.4.3. *Factors influencing road user risk perception, attitudes and beliefs*

Eight studies (11%) identified factors influencing road user risk perception, attitudes and beliefs. The factors identified in the studies as influencing these outcomes are shown in Fig. 6. No relationships between factors were identified within the studies.

The figure shows that the factors found to influence risk perception, attitudes and resided predominantly at the *physical processes and actor activities* level ($n = 17$; 68%). The most frequently identified factors included location of the RLX, younger road users, and knowledge of the road rules pertaining to RLXs.

4. Discussion

This review aimed to determine what is currently known regarding the main factors influencing risk at RLXs, with a focus on understanding the causal relationships across the entire sociotechnical system. A total of 88 studies published over a 30-year period from 1989 to 2019 were identified via a systematic review protocol. Most studies were published as journal articles, indicating that there is a good level of scientific rigor in the research being undertaken to meet the standards of peer review. In relation to the geographical context, while the studies were conducted across various countries, a large proportion were conducted in Australia, North America and Canada. This is interesting given the high rates of collisions and trauma across Europe (European Railway Agency, 2017; Office of Rail Regulation, 2018).

Most studies focused on drivers, rather than investigating pedestrians and/or all road users together. Given that statistics show that safety improvements have occurred in relation to vehicle-train collisions

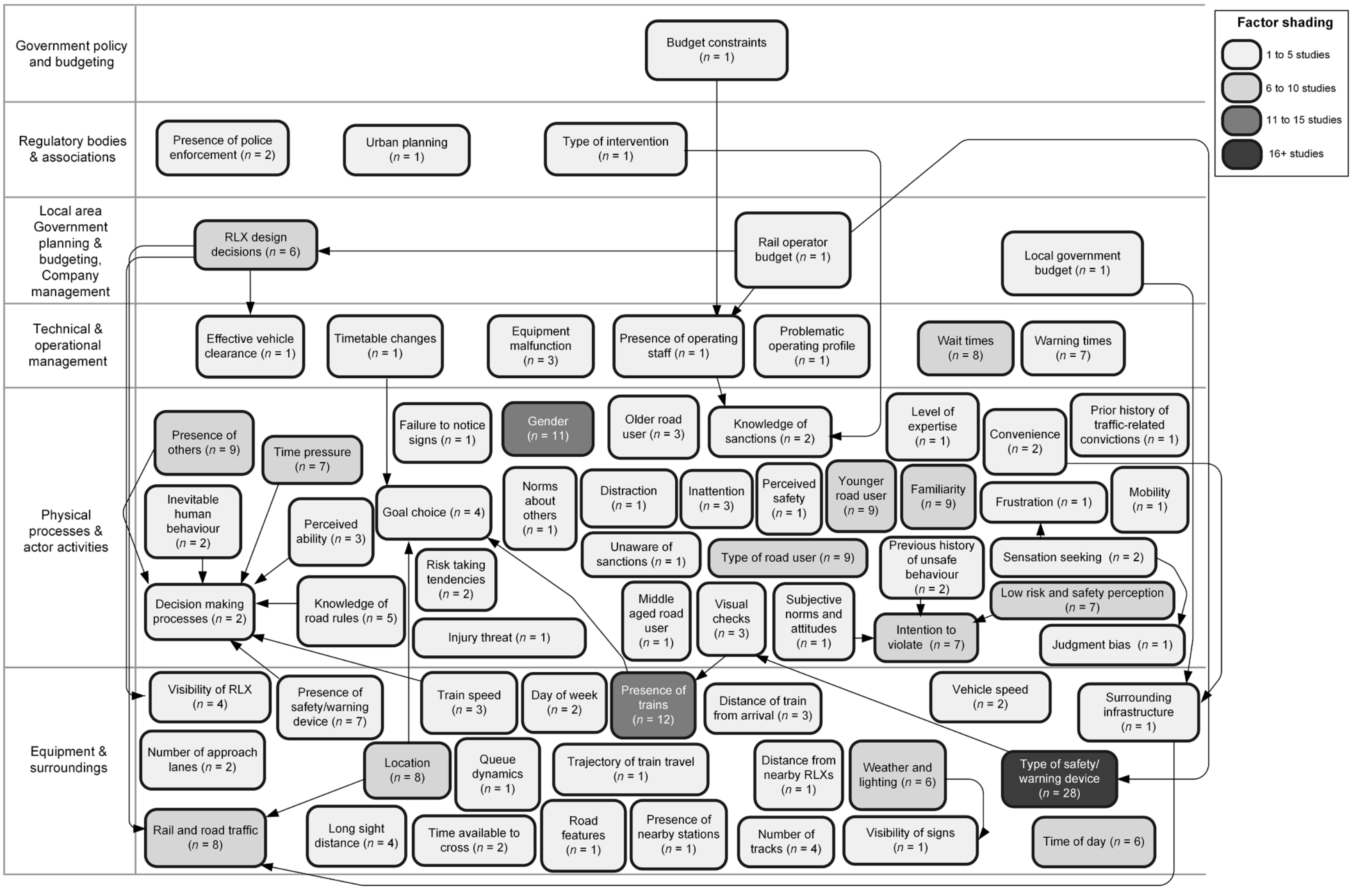

Fig. 5. AcciMap of factors influencing unsafe and non-compliant road user behaviours ($n = 67$). Note, each relationship between two factors shown with arrows were identified within only one study.

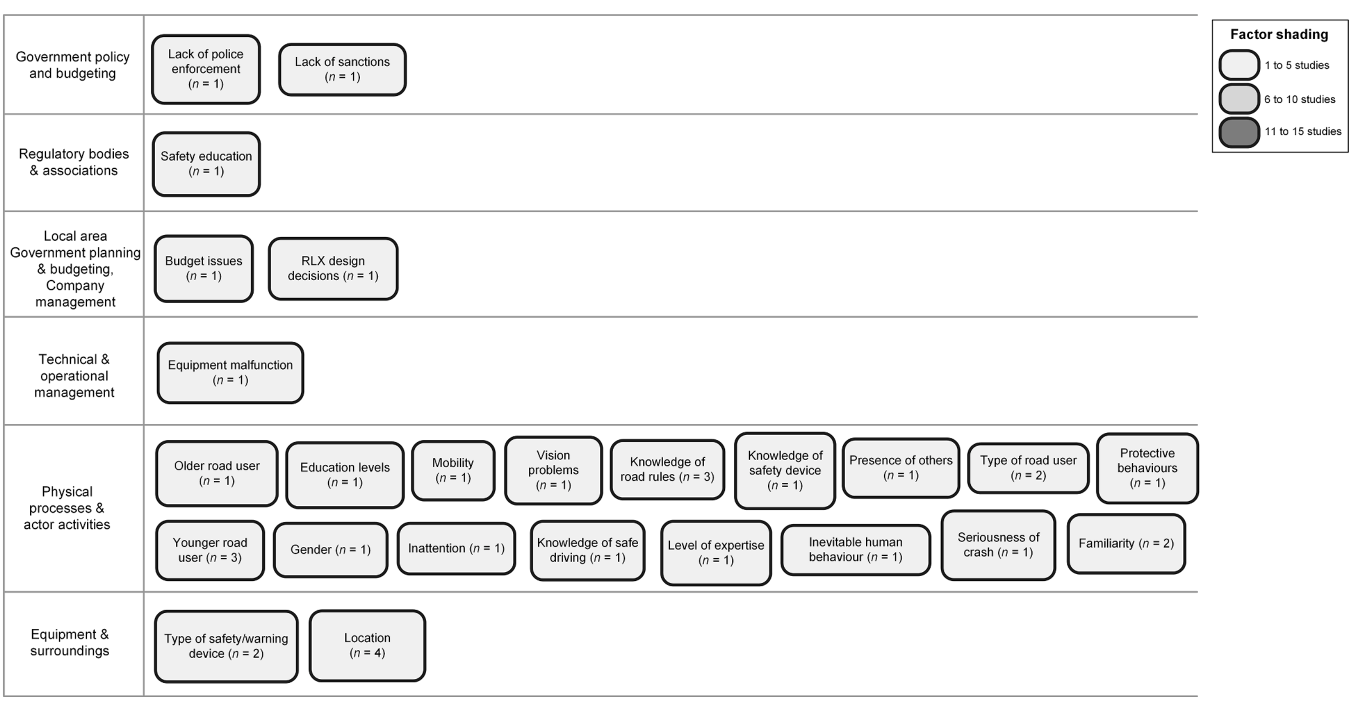

Fig. 6. AcciMap of factors influencing road user risk perception and attitudes and beliefs ($n = 8$). Note, each relationship between two factors shown with arrows were identified within only 1 study.

at RLXs, but not in pedestrian-train collisions (Metaxatos and Sriraj, 2013; Stefanova et al., 2015b) and that pedestrians have more latitude for behaviour in relation to non-compliances (i.e. circumventing pedestrian gates through the emergency exit gates, crossing via the roadway or tracks), further research with a focus on pedestrians is recommended. Efforts to better understand pedestrian behaviour are already underway as shown by the increasing rate of consideration of pedestrians within more recent studies identified in the review. This likely reflects a more general interest in vulnerable road user safety and the interactions between road users in the broader road safety literature (e.g. Aldred, 2018; van Haperen et al, 2019). However, further research is needed into pedestrian attributes that can increase risk at RLXs such as having a visual, auditory or mobility impairment, as well as behaviour such as the use of distracting technologies. In addition, given current and projected increases in urban populations, cyclists and users of emerging forms of transport such as e-scooters need to be considered.

The review identified that most of the studies were descriptive in nature. That is, they aimed to describe the current state rather than determine associative or causal effects. Studies in this category involved focus groups or interviews to understand road user attitudes, observations of road users at RLXs, or the retrospective analysis of the factors involved in accident case studies. While such studies are useful, the relative lack of epidemiological and experimental research designs hinders our understanding of the causal relationships amongst factors.

The AcciMaps demonstrate that a large number of influencing factors have been identified across the three types of outcomes. This demonstrates the complex nature of the RLX system, where heterogenous factors from across system levels create the conditions for crashes to occur. However, the factors identified in the literature to date are biased towards appearance at the lower levels of the system. The majority of identified factors were at either the *equipment and surroundings* level which relates to the physical RLX environment or the *physical processes and actor activities* level which generally relates to road user behaviour. This means that the focus of the literature has been the physical attributes of the crossing itself, its operation, and the behaviours and demographic and psychological attributes of road users. For example, the most frequently identified factors included the type of safety or warning device in place at the crossing, the presence of a train at the crossing, and the gender of the road user. While some factors were identified at the higher levels of the RLX system, more research is needed to capture the full range of systemic factors that play a role in influencing road user behaviour and maintaining safety at RLXs. This also suggests that little progress has been made in implementing systems thinking approaches in research relating to risk at RLXs (Read et al., 2013). This is concerning given that it has been argued that a failure to consider the overall RLX system will prevent significant safety gains (Read et al., 2017; Salmon et al., 2013). Better understanding the systemic factors can identify leverage points to improve RLX safety, regardless of the particular attributes of any specific RLX context or road user.

The review highlighted a noteworthy gap in the literature relating to the lack of consideration of relationships between factors. This is arguably a critical requirement in any research attempting to understand behaviour in complex systems. Indeed, a key tenet of systems thinking is that behaviour can only be understood by examining the interactions between system components (Ottino, 2003). Although relationships were identified between some factors in the AcciMaps, each connection was drawn from a single study only, meaning the findings have not been replicated. The lack of research examining the relationships between contributory factors or behavioural influences is thus identified as an important area for future research. Therefore, there is significant work to do in creating a truly holistic picture of how factors across the RLX system combine to create accidents.

4.1. Limitations of the review

An important consideration in generalising the findings of the literature is that there may be contextual, operational, geographical and cultural differences that impact on behaviour and outcomes. For example, an investigation into the effectiveness of warning devices in a rural environment in the USA may not be applicable to an inner urban crossing in Australia due to different usage patterns, road user types, types of warning devices, or road rules in place. Thus, care needs to be taken in applying findings without consideration of the local context.

Conversely, studies not available in English language were excluded from the review. Therefore, the findings of studies from geographically and culturally diverse contexts may not have been fully covered. This should be considered when generalising the results outside of English-speaking countries.

Finally, this study adopted a comprehensive systematic search strategy which involved covering academic databases and grey literature indexed in transport industry databases. However, given the nature of applied/industry research and existence of work in other languages, there may be publications relevant to risk at RLXs that were not identified in the search.

4.2. Practical implications and future research directions

In terms of its practical implications, this review suggests that ongoing research in this area would benefit from adopting a more overt systems thinking perspective and the use of systems-based methods to identify and address factors influencing risk all levels of the RLX system, including how the factors interact to influence accident risk.

In view of this, we propose that an integrated approach may be achieved through consideration of a ‘many model’ approach to better understand risk at RLXs and then reduce the risk of adverse incidents through the development and evaluation of systemic interventions. Such an approach has recently been applied in road safety (Salmon and Read, 2019). Advocates of the many model approach argue that when dealing with complex problems, multiple models assist in developing a better understanding of the problem through methodological triangulation to support the creation of more comprehensive and sustainable interventions (Page, 2016; 2017).

Table 3 outlines a potential many model approach for improving RLX safety. Encouragingly, some of the analyses to contribute to the approach are already available. A key criticism of these initial studies, however, is that they describe behaviour within the system, but do not link this to risk at RLXs. The proposed many model analyses could begin with the use of existing knowledge and data to analyse the problem (Stage 1), of which the findings of this review would be an initial data source. These review findings could be extended through analyses of contributory factors identified in RLX accident investigation reports and Coronial investigations into fatalities at RLXs. The process would then involve an analysis of RLXs focussed on their normal functioning (Stage 2), using methods such as the Systems Theoretic Accident Model and Processes (STAMP; Leveson, 2004) and the Work Domain Analysis (WDA) phase of Cognitive Work Analysis (CWA; Vicente, 1999). An existing WDA of the RLX system is available to contribute to this stage (Read et al., 2017), however as noted in Table 3, at this early stage of the many models approach the modelling is focused on describing the functional structure of the system, without identifying factors influencing risk.

The next phase (Stage 3) would involve analysing behaviours and interactions between actors (individuals, technologies, organisations) at different levels of the system using the network-based approach, the Event Analysis of Systemic Teamwork (EAST; Stanton et al., 2013). Again, aspects of EAST analyses have already been conducted (Salmon et al., 2018; Read et al., 2018), although further work is needed to create a full complement of networks that address:

- Multiple system levels (e.g. interactions amongst RLX users and technologies at RLXs; interactions between road and rail agencies who coordinate to manage risk);

Table 3
Overview of proposed research agenda.

Stage	Potential method/s	Data sources	Expected outcomes
1. Analysis of problem using existing knowledge and data	AcciMap: Identifies contributory factors and relationships between them across a sociotechnical system	- Existing literature on factors influencing risk at RLXs (i.e. findings of this review) - Accident investigation reports - Coronial reports	- Insights from individual cases - Data/trends based on aggregation of individual AcciMaps, including insights into common failure pathways based on relationships
2. Analysis of the system in which the problem occurs	STAMP: Identifies the actors involved in maintaining safety and the control and feedback relationships between them. WDA: Identifies the functional structure of the RLX system	- Subject matter expert input	- Insights for improving system design - Identification of constraints on potential interventions
3. Analysis of behaviour in scenarios in which the problem occurs	EAST: Models the behaviour of individuals, teams, organisations, and systems using task, social and information networks.	- Existing literature on RLX user behaviour - Empirical data from observations, walk-throughs, interviews, focus groups, documentation review	- Insights into interactions and coordination across actors at different system levels and how this can lead to risk
4. Design of interventions	STS-DT: Design of systemic interventions informed by insights gained from previous stages (AcciMap, STAMP, WDA, EAST)	- Subject matter expert participation in development of interventions	- One or more systemic interventions for improving RLX safety
5. Modelling of impact of interventions on risk over time	System dynamics: Analyses the behaviour and dynamics of complex systems over time	- Subject matter expert input and review	- Evaluation of the potential effects of interventions over time on risk at RLXs

Note: STAMP = Systems Theoretic Accident Model and Processes; WDA = Work Domain Analysis; EAST = Event Analysis of Systemic Teamwork; STS-DT = Sociotechnical Systems Design Toolkit.

- All road user types, including vulnerable and emerging road users such as pedestrians, cyclists, motorcyclists and e-scooter riders; and
- The relationship between interactions and risk at RLXs (i.e. specify how interactions might contribute to the risk of crashes).

Once these analyses have been conducted, design approaches can be used to translate the insights from the previous analyses and to create new systemic interventions to address the RLX risk problem (Stage 4). Previous work has applied methods such as a design toolkit to re-design the physical level crossing environment in a participatory manner with subject matter experts (SMEs; Read et al., 2017). However, being conducted outside of a many models approach, this was not based on a formal analysis of the problem using a method such as AcciMap and was therefore limited in its scope to trace design interventions to RLX risk scenarios. Future applications of the design toolkit within the proposed many model approach should clarify this, and also address the systemic drivers of risk at RLXs. The effect of new interventions on risk could also be demonstrated using computational modelling methods such as System Dynamics (Sterman, 2000), for the first time in this area (Stage 5). System Dynamics involves modelling the behaviour and dynamics of complex systems over time, focusing on reinforcing and balancing loops that connect variables within a system. This approach has been used previously to forecast the potential effects of interventions for drink driving (Salmon et al., 2020) and to compare the impacts of policy approaches to land use and transport on health outcomes (McClure et al., 2015). Salmon and colleagues (2020) also argue that methods such as CWA, AcciMap and STAMP provide useful inputs when developing system dynamics models and help to ensure model validity.

From a practical perspective, the research agenda described here may be supported by ensuring that accident investigations and coronial investigations identify contributory factors at all levels of the system, as well as capturing and reporting the relationships between factors. Such information could be aggregated within accident and crash databases to enable on-going review and monitoring of factors influencing risk at RLXs. Making this link between influencing factors and adverse events such as crashes is vital to ensure that systems thinking approaches are valid in identifying and addressing appropriate factors to reduce risk.

5. Conclusion

Preventing crashes and near misses at RLXs is a key public safety concern due to the significant financial and societal impacts caused by these events. Accident prevention in complex systems requires an understanding of the factors across the whole system that increase the risk of these events. This review contributes to the knowledge base in two ways. First and foremost, it identifies that little progress has been made in implementing systems thinking approaches to understand and address risk at RLXs. Second, and to go some way towards addressing this gap, it outlines a research agenda describing how the knowledge may be used within a wider research framework to understand the RLX problem, followed by the use of other data and systems thinking methods to identify and then evaluation systemic interventions. We hope that this review inspires greater use of systems thinking approaches in effectively understanding and addressing risk at RLXs.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2021.105207.

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