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A review of models relevant to road safety

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ABSTRACT

It is estimated that more than 1.2 million people die worldwide as a result of road traffic crashes and some 50 million are injured per annum. At present some Western countries' road safety strategies and countermeasures claim to have developed into 'Safe Systems' models to address the effects of road related crashes. Well-constructed models encourage effective strategies to improve road safety. This review aimed to identify and summarise concise descriptions, or 'models' of safety. The review covers information from a wide variety of fields and contexts including transport, occupational safety, food industry, education, construction and health. The information from 2620 candidate references were selected and summarised in 121 examples of different types of model and contents.

The language of safety models and systems was found to be inconsistent. Each model provided additional information regarding style, purpose, complexity and diversity. In total, seven types of models were identified. The categorisation of models was done on a high level with a variation of details in each group and without a complete, simple and rational description. The models identified in this review are likely to be adaptable to road safety and some of them have previously been used. None of systems theory, safety management systems, the risk management approach, or safety culture was commonly or thoroughly applied to road safety. It is concluded that these approaches have the potential to reduce road trauma.

1. Introduction

Road traffic injury is listed in the top ten major causes of mortality and morbidity worldwide (WHO, 2010). It is estimated that more than 1.2 million people die as a result of road traffic crashes and some 50 million are injured per annum (WHO, 2009). Road safety strategies are developed to choose, guide and describe actions to reduce this burden of injury. Road safety strategies focus on road users, vehicles, roads, and socio economic factors (Haddon, 1980). Recently, road safety strategies have been described as being a safe systems approach (Wegman et al., 1995; OECD, 2008).

Strategies to understand and reduce accidents and injuries have been developed in many domains, for example in occupational health (Rasmussen, 1980), hazardous industries (Johnson, 1980) and other modes of transport (Gibson, 1961; Helmreich and Merritt, 1998), thus being applied to different contexts. Types of safety models from these and other fields may be applicable to road safety but do not meet the description of a system (Wilson, 2014a; Perrow, 1984; Leveson, 2004). The full range of safety model types which may be applied to road safety strategies, such as the safety management system (Standards Australia and Standards New Zealand, 2001a,b) are not evident in road safety. Therefore, other types of model may potentially be applied to improve road safety strategies. In order to determine whether that is the case or not, the different types of safety models need to be categorised according their characteristics and compared. If however, the range is known, then the most appropriate model type may be used to develop more comprehensive and effective road safety strategies.

1.1. Models

A 'model' is a simplified description or representation of something to assist understanding. Models assist in creating a mental picture, facilitate questioning and information, establishing rules, checking, evaluation, analysis, identifying and assessing

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countermeasures and communication (Kjellén, 2000). Physical, visual, mathematical and descriptive models have been constructed for a variety of purposes. In this review, models are defined as concise descriptions of a whole entity, variously called models, frameworks, concepts or other terms. In this case, the purpose of applying the models was to explore possible ways to improve safety. At the highest level, these models are generally descriptive, often with a visual aspect (diagrammatic), rather than the more detailed mathematical and quantitative models used for particular analytical purposes. The utility of models is dependent on the context and application, and therefore it is important to recognise the distinction between descriptions (the models) and how they are applied (a process) (Underwood and Waterson, 2013a). Models are not perfect, neither in description, nor in application, which leads to criticism and conflicting preferences between proponents or practitioners (Underwood and Waterson, 2013a). Weaknesses in high level models are often overcome by the application of more specific analytical techniques (Underwood and Waterson, 2013a). The present review considers models of safety at a high and holistic level. However, the term model is ambiguous and may be applied in other ways, such as those used for quantitative analysis or simulation, or qualitative descriptions of principles or concepts, as described below.

Taxonomy of types of models is rare in the literature. System theory, energy models, process models, information-psychology theories and other approaches have been applied (Kjellén and Larsson, 1981) but not categorised. There is reference to types of research where data sources were broadly classified as accident analysis, field studies, questionnaires of safety participants, expert opinion, theory or literature, and simulator studies (Hale and Hovden, 1998). Studies have also classified by purpose (e.g., model, audit, analysis tool, training, etc.) and in finer detail by topics included in the study (e.g., structural, human resources, political or symbolic) (Hale and Hovden, 1998), originally being devised for categorising organisational purpose (Bolman and Deal, 1984). Experimental, ethnomethodological and survey research types have been proposed for ergonomics research (Dekker and Nyce, 2010). However, such approaches are neither holistic nor systematic classifications of all possible models of road safety at the strategic level, and thus excluded from the current review.

1.2. Systems concepts

Systems concepts are highly influential in safety, although the term 'system' is widely, but inconsistently used (Waterson, 2009). Furthermore, studies suggest that applying systems concepts techniques provide a deeper understanding of how dynamic, complex system behaviour contributes to accidents, resulting in better safety outcomes (Underwood and Waterson, 2013b). The term 'system' and its related concepts may be defined variously and used differently depending on its situation, users, foundational theories and application (Underwood and Waterson, 2013a). While not unambiguously defined, the literature describes:

i. system (an operating entity),
ii. systems theory (an underlying rationale for definition of systems characteristics),
iii. systems approaches (a process to analyse and understand a system), and
iv. systematic processes (a manner of application).

There is a general agreement that systems involve the processes of transforming input to output for a purpose, but a deep and broad conceptualization of systems theory and its application is lacking (Waterson, 2009; Wilson, 2014b). A system may exist and be investigated in non-systematic ways or not according to systems theory. A systems approach to analysis (or process) would be consistent with systems theory and should be systematic, but other approaches to analysis may also be consistent with systems theory, without necessarily following the thorough systems approaches described in the literature. However, a thorough description of these differences and the variations in different literature is beyond the scope of the present review, but summarised below.

Systems theory is a scientific exploration of wholeness, covering various constituent elements and their relationships (Von Bertalanffy, 1968). Systems theory challenges reductionist views and analysis, which attempts to draw information and conclusions of certain sections in isolation from other parts of the system. Systems theory describes that systems exist when there are interdependent, but related components achieving a valued pre-set objective, purpose or function (Wilson, 2014a; Leveson, 2004; Perrow, 1984). According to system theory, the fundamental constructs of a system are components, relationships, joint purpose and interdependency, which may be complemented by other descriptive principles or dimensions, such as time. These characteristics are used to describe a system, proving a system model. However, other models may also exhibit characteristics of systems.

A systems approach to safety is a process which views accidents as the result of unexpected, uncontrolled relationships between different parts of the system, instead of being limited to traditional cause-effect accident models (Underwood and Waterson, 2013b). Importantly, in this approach, systems are analysed as whole entities, rather than considering their parts in isolation (Underwood and Waterson, 2013a; Waterson, 2009). Systems approaches may be described by principles, characteristics, processes or constituent parts. The systems approach offers the benefits of understanding and consideration of the whole subject, providing a deeper knowledge on how dynamic, complex system behaviour contributes to accidents (Underwood and Waterson, 2013b). As a method, it is comprehensive, rigorous, founded in theory and proven in practice. Other approaches may be more reductionist and overly simplistic in assessing individual aspects in isolation, ignore complementary effects and interdependence or not yet be demonstrated to be valuable. Systems theory and techniques have successfully been applied to improve safety in the most complex operations and situations including aviation, rail transport, nuclear power and health (Waterson, 2009) and aerospace, production industry, water supplies, and the military (Leveson, 2011). Any investigation or analysis may be conducted systematically without recognising any system characteristics. Systematic investigations are logical, thorough and robust. Some of the clearest systematic approaches are systematic literature reviews (Cochrane Reviews, 2011), which may not relate to a system as understood in system theory or safety as a particular outcome.

Applying systems theory and systems approaches have been accepted as being meaningful despite the lack of widely accepted explanations of exactly what this means in relation to theory, principle and practice (Waterson, 2009; Wilson, 2014a). Some safety procedures have been codified based on accepted principles or practical expertise and judgement from experienced practitioners, but have little or no scientific basis (Hale and Hovden, 1998). The limitations of traditional cause-effect accident models have been acknowledged, but the use of system models is not always considered appropriate (Underwood and Waterson, 2013b) depending on the application, organisational culture, an individual's previous experience and training or availability of data. Therefore systems theory and systems approaches should be applied more thoroughly.

1.3. Models relevant to road safety

Several types of models have been used to understand and improve road safety. However, the justification for the choice of

Table 1
The stepwise search process for articles and books.

Step	Article search	Book search[a]
1.	Definition of the review question, selection of search terms and development of criteria for searches	
2.	Preliminary scan of search results	Identification of potential suitable books from search results and articles
3.	Initial search selection of search and download of summary information	Request suitable books from external sources
4.	Refine search to reduce size	Identify library book sections for shelf scan
5.	Elimination of duplicates in two stages	
6.	Initial information selection based on relevance, quality and potential value, sequentially by title then abstract and papers in English	
7.	Collect and review potentially relevant papers	Scan books to identify relevant information
8.	Discard papers without useful information	Retain books with useful information
9.	Identify and summarise useful models	

[a] Including government reports.

type of model and the relative utility of different types of models have not been described. System models are one of the full range of available types investigated in the present review to find out if they are relevant and applicable to improve road safety strategies.

While systems theory and systems approaches have been applied to several transport safety domains including aviation and rail (Waterson, 2009) and for specific situations in road safety (Read et al., 2013), a comprehensive understanding about systems theory is not evident in road safety at the strategic level. Systems approaches to road safety at the strategic level are rare despite the limitations of traditional, reductionalistic approaches which a systems approach could overcome (Larsson et al., 2010). The few references to thorough applications of systems theory and systems approaches to road safety mainly relate to individual incidents or analysis (Read et al., 2013; Salmon et al., 2012; Goh and Love, 2012).

The systems approach to safety is based on systems theory applicable to analysing various performance and operating aspects, such as efficiency and safety, which have been evaluated in practice. In contrast, the 'safe system' approach applied to road safety strategy is based on philosophical positions, such as ethical arguments, and evidence from practical experience with road safety countermeasures, such as limitations of the human body to tolerate transfers of kinetic energy, rather than on a theoretical basis.

2. Methods

The current review searched models from a wide variety of fields and contexts that are potentially applicable to road safety. A stepwise review of the safety strategies described in peer and non-peer reviewed scientific literature was carried out based on a variety of similar procedures (NHMRC, 2000; Cochrane Reviews, 2011; Petticrew, 2001), as summarised in Table 1.

Eight databases were used; The Cochrane database, EBSCO HOST, Embase, Informit, Medline, ProQuest, Web of knowledge and Safety Science and Risk Abstract.

The databases were searched for relevant literature with no limitations to the year of publication or contexts such as industry, health transport or recreation. The following search terms were used:

i. safety or accident (being the antonym of safety) and
ii. system, framework, strategy, policy or model.

Using pairs of these two types of terms yielded 10 pairs for 8 databases, with a total of 110 initial searches. The search pairs safety + model, safety + system, accident + model, and accident + system with these terms in the article title were examined, which yielded the 11,334 results, summarised in Table 2, for which the endnote summary information was downloaded. Duplicates were eliminated, which resulted in a total of 2620 unique records.

A set of criteria was used to filter out articles retrieved from the databases, deemed to be of little value or relevance. This included:

- literature that was too specific to provide information at the system (macro) level,
- generalised models used in non-safety contexts (such as strategic or operational business planning, total quality management or other processes),
- specialised assessments, tools, techniques or models for detailed and specific analytical purposes,
- literature that was too vague to be considered as a coherent model description,
- literature originating from ambiguity of terms (such as a document on insurance policies instead of other policy),
- book reviews, letters to journals, and editorials offering no new information, or
- formal industry standards or legislation described within legal frameworks or regulatory models.

Following the process described in Table 1, the summary information from the remaining 2620 documents was scanned. Of these, 557 full text documents were sourced and reviewed, and 121 models describing different content were summarised (Appendix A). Finally, the models were categorised based on the characteristics which described them. A widely applicable taxonomy of model types, not previously evident in the literature, was developed to categorise as many of the models as possible. Models which used for road safety purposes were specifically identified. Most models were characterised by one of seven types, but some contained additional descriptive information which did not fit into these types.

3. Results

3.1. Safety models

Models of safety are widely applied to industrial, transport, government and personal situations to describe a level of likelihood and adverse consequence of expected or unexpected events (Reason, 1990), but were found to be poorly defined. Terms such as safety, risk, hazard, and accident were often used interchangeably, with or without clear definition. The diversity of types and content of models developed to describe and investigate safety issues and develop responses are summarised in Table 3.

Table 2
Initial searches from which information was downloaded in August 2011 (papers numbered in brackets with * were not downloaded).

Databases (see below) search terms	1	2	3	4	5	6	7	8
Safety + model	32	(315*)	(635*)	264	(519*)	(379*)	(3148*)	519
Safety + system	119	(131*)	(974*)	315	(776*)	(926*)	(8509*)	528
Safety + strategy	35	252	366	386	271	201	734	179
Safety + policy	9	523	267	334	245	280	697	943
Safety + framework	0	65	94	77	72	65	286	98
Safety + model + system		28	18		12	29	298	
Safety + model + strategy		1	7		6	4	17	
Safety + model + policy		7	1		1	4	7	
Safety + model + framework		2	7		7	0	13	
Safety + system + strategy		7	12		9	7	40	
Safety + system + policy		16	6		3	5	30	
Safety + system + framework		5	2		2	0	44	
Accident + model	2	109	162	204	135	71	(856*)	226
Accident + system	4	85	134	131	126	78	(878*)	79
Accident + strategy	2	16	28	24	26	17	157	26
Accident + policy	2	105	34	56	31	39	150	17
Accident + framework	0	9	4	5	10	2	45	5
Accident + model + system							47	
Accident + model + strategy							3	
Accident + model + policy							1	
Accident + model + framework							2	
Accident + system + strategy							7	
Accident + system + policy							3	
Accident + system + framework							2	
Total	205	1230	1142	1796	956	802	2583	2620

Database	Sub-database included and notes
1. Cochrane	Reviews
2. EBSCO HOST	Business Source Complete, EconLit, ScoINDEX
3. Embase	1988–July 2011
4. Informit	APA-FT, APAIS-Health, AMI, ATRI, Health Collection, Health and Society, Humanities and Social Sciences Collection, RURAL
5. Medline	1948–2011
6. ProQuest	Central – journals, reports, books, dissertations and working papers
7. Web of knowledge	
8. Safety science and risk abstract	Conference papers, books and peer-reviewed journals

3.2. Model types

Seven different types of safety models were identified, arising from different domains, purposes, uses, characteristics or perspectives. Some models described the component parts, such as the human–machine–environment model. A second group summarised the how the sequences of events and activities which existed or contributed to adverse events may have been changed. A third group of models was described by individual interventions used to improve safety, such as engineering, education, enforcement and encouragement. This group was closely aligned with, and often occurred with analytical or quantitative models for assessing the interventions. Another group of models represented the sequence of events by which the adverse outcome occurs. Some models described comprehensive safety management systems or risk assessment processes by which safety may be analysed and managed, although the descriptions were not directly related to the theoretical descriptions of systems as described earlier. A final group was described as a systems approach, although again, not all of these were related to theoretical descriptions of systems. These groups covered the majority of models identified although some models fell outside the categories.

The models had evolved and changed over time. Early models tended to focus on the components contributing to activities or safety. Later emphasis was on interventions, quantitative analysis, work processes and failure sequences. The most recent models adopted systems terminology, particularly for management of safety. Some of the models identified were seminal, and had become the foundations for safety concepts and risk management, referred to or used as a basis many times.

Models were identified from a great variety of fields including all major modes of transport, general industry, hazardous industries, health and recreation. Some models were at a high level of a whole country, while others were for specific locations such as for recreation centres. Component models, sequence models, intervention models and mathematical models have been applied to road safety. System models safety management models from other domains have not yet been applied to road safety. Each of the seven model types potentially offers advantages and disadvantages by describing the safety situation in quite different ways, which is further addressed below.

3.3. Additional supporting information

In addition to structured simplified models constructed to improve understanding, further useful information was found. It included the theory and rationale underlying safety models (Von Bertalanffy, 1968; Wilson, 2014a), reasons for models (Waterson, 2009; Leveson, 2004, 2011), approaches to structure or type (Attwood et al., 2006), principles (Johnson, 1980), assessment or evaluation (Benner, 1985), and applicability or relevance to contexts or situations. There were fundamental differences in the underlying basis of the models, such as whether human failure is something to be accepted as inevitable, or if it can be managed and improved. Any of the models could include additional valuable information about definitions, principles, objectives, targets, or other content, but was not necessarily specific to a particular domain, model type or context.

3.4. Two important terms

In addition to the model and system, safety culture also emerged from the review as an important concept. The review particularly highlighted issues with respect to these latter two terms.

Table 3
Examples of different types of safety models.

Model type	Characteristics of model type	Examples of the model type
1. Component models	Identifies all the individual contributing parts or units.	Gordon (1949), Gibson (1961), Haddon (1968[a], 1972[a], 1980[a]), Fell (1976)[a], Rasmussen (1980), Rasmussen (1982), Rasmussen (1997), Heinrich et al. (1980), Johnson (1980), Booth (1980)[a], Poole (1986), Grey et al. (1987), Embrey (1992), McGraw et al. (2008), Burns and Machado (2009)
2. Sequence models	Based on a specific series of events resulting in incident(s) (e.g., event chain, energy transfer and fault tree analysis).	Haddon (1968[a], 1972[a], 1980[a]), Heinrich et al. (1980), Johnson (1980), Cameron (1992)[a]
3. Intervention models or	Identifies activities or countermeasures which improve safety (e.g., engineering, enforcement).	Johnson (1980), Rasmussen (1982), Loader and Hobbs (1999), Standards Australia and Standards New Zealand (2001a,b), Pun and Hui (2002), Hirasawa et al. (2005)[a], Newnam and Watson (2011) *(Note these models have characteristics of both Intervention and Mathematical models)*
4. Mathematical models	Based on quantitative analysis of data and relationships.	
5. Process models	Identifies sequences of, and relationships between work and/or activities.	Blake (1963), Heinrich et al. (1980), Rasmussen (1982), Reason (1990), Sauter et al. (1990), Childers and Rohrer (1992), Stang (1996)
6. Safety management models	Identifies management components, system, relationships and outcomes. Describes the manner and process by which safety is managed (e.g., safety management system or risk management system).	Gibson (1961), Blake (1963), Glass et al. (1979), Heinrich et al. (1980), Johnson (1980), Rasmussen (1982), Childers and Rohrer (1992), Wegman et al. (1995)[a], Weinstein (1996), Glendon and Waring (1997), Redinger and Levine (1998), GAO (2006), Standards Australia (2006a,b), Bellamy et al. (2008), McGraw et al. (2008), Makin and Winder (2008), Burns and Machado (2009), Whitefield (2009), Holló et al. (2010)[a], Hsu et al. (2010), Ball (2011), Black et al. (2011)
7. System models	Describes purposes, components, relationships and interdependency.	Johnson (1980), Stang (1996), Porter and Wettig (1999), Standards Australia and Standards New Zealand (2001a,b), Leveson (2004), Australian Transport Council (2004)[a], Burns and Machado (2009), Whitefield (2009), Larsson et al. (2010)[a], Salmon et al. (2012)[a], Goh and Love (2012)[a], Read et al. (2013)[a]
Additional supporting information		
Definitions, principles, objectives and targets		Gordon (1949), Glass et al. (1979), Haddon (1980)[a], Heinrich et al. (1980), Rasmussen (1982), Perrow (1984), Poole (1986), Donegan et al. (1989), Reason (1990), Glendon and Waring (1997), Redinger and Levine (1998), Standards Australia and Standards New Zealand (2001a,b), GAO (2006)
Other framework concepts and information		McGraw et al. (2008), Whitefield (2009), Burns and Machado (2009), Wallis and Dovey (2011), Miller et al. (2011), Ball (2011)[a]

[a] Examples of model type applied to road safety.

3.4.1. *Systems properties*

Only a few models defined terms thoroughly. The term system, described by Perrow (1984), Leveson (2004), Underwood and Waterson (2013b) and Waterson (2009) was particularly problematic, being widely and differently used without clear definition. As mentioned, systems theory describes four key attributes; the components of the system, interrelationships between components, the system's purpose and interdependency between components. Additionally, these attributes may be based on an underlying theory and supported by principles. While regularly used in the literature, the term system was generally not used consistent with a theoretical approach or in another well-defined or justified way.

3.4.2. *Safety culture*

The term 'safety culture' emerged as a strongly supported concept used to describe the underlying nature of an organisation's approach to safety. Safety culture was described as a characteristic, property or component of systems, rather than a model in itself (Hale and Hovden, 1998; Helmreich and Merritt, 1998; Morley and Harris, 2006). A healthy safety culture is multi-dimensional with well-developed norms and rules to promote safety, an informed and healthy attitude towards risk, and possessing mechanisms to provide feedback concerning safety performance (Morley and Harris, 2006). However, the term safety culture was poorly defined, described inconsistently and used in different ways across the literature. Nevertheless, safety culture has apparent potential to contribute to understanding to improve safety in a system.

3.5. *Comparison of types of model*

The seven different types of strategic safety model were compared according to purpose, use, characteristics, strengths, weakness and relevance to road safety, as shown in Table 4. The strengths and weaknesses were substantially assessed against systems characteristics (holistic, relational descriptions, components and purpose). Purposes particularly considered four organisational aspects: structural, human resource, political and symbolic (Hale and Hovden, 1998; Bolman and Deal, 1984).

While the form of the frameworks may be categorised as above, the content within each description could vary widely. For instance, the Component Model of host, agent and environment used for epidemiological assessment (Gordon, 1949) was quite different to Haddon's matrix (Haddon, 1980) used for road safety, which included human, vehicles and equipment, physical environment, and socio-economic environment components. Therefore, the types of model categorised in Table 3 covered a wide range of specific models.

Comparing the attributes of models based on systems theory with the models classified in Table 3 (and described in Appendix A)

Table 4
Comparison of different types of safety models.

Model type and purpose	Model use	Strengths	Weaknesses	Relevance to road safety application
1. Component models For development and assessment of strategies, policies and programmes for countermeasures	Used in safety strategy development Provides a structure for general safety information Provides general descriptions	Holistic, enabling identification of specific unit weakness and general countermeasures Describes contributions to purpose Categorisations of components may vary (e.g., physical, organisational or activities) Can describe human resources and structural aspects	May not describe relationships between elements Unlikely to cover political or symbolic aspects Difficult to assess risk or causes of failure Difficult to analyse activities or processes May not be sufficiently specific or detailed Difficult to identify specific hazards Difficult to describe all outcomes May be difficult to move between domains	Road safety components often described as four E's: engineering, enforcement, education, encouragement Safe systems approach of vehicles, roads, drivers has been applied
2. Sequence models For determination of cause and countermeasure development	Used for individual incident/accident analysis	Describes contribution to failure rather than contribution to purpose Focus on proximate causes, interfaces and time Good examination at micro level Detailed descriptions of relationships between directly contributing components, including human factors	Difficult to apply to large, non-linear and complex systems with many components and interactions, at strategic level Unlikely to cover political or symbolic aspects Often subjective with evidence base restricted to event Does not take account of context or holistic effects Difficult to apply to a series of small contributing failures Often limited by a start and end time or part of sequence Difficult to include whole-of-system factors (e.g., organisational safety culture or factors outside the organisation or span of control Often restricted to identifying cause, blame or prosecution	Used to analyse specific types of crashes or interventions Not used at strategic level
3. Intervention models For development and assessment of strategies, policies and programmes for countermeasures	Used to analyse specific policy or strategy	Relates directly to agency roles, contribution and responsibilities Based on generalised causes Can be used to describe outcomes Can recognise human resources and structural aspects Strong understanding of outcomes	May not describe relationships between activities or recognise all contributing components May be too specific and insufficiently holistic May be difficult to assess specific risks or causes of failure Unlikely to cover political or symbolic aspects	Used as impact analysis or cost-benefit analysis of specific interventions Could be applied in assessment of the whole system
4. Mathematical models For investigation of systems, events, risks and countermeasures	Used for quantitative analysis of effects of specific policy or strategy	Provides strong evidence basis Powerful evidenced based tool for influencing and making decisions Suits detailed micro analysis Strong understanding of relationships and outcomes	Generally focuses on only one very specific element or issue Likely to be too specific, insufficiently holistic and not recognise all components Needs to be conducted with consideration of the whole context Unlikely to cover political or symbolic aspects Can be difficult to apply if data is not available or analysis becomes impossible Risk of being too narrow resulting in justifying preconceptions, or what-you-see-is-what-you-find	Many different types including typical statistical analysis, epidemiological, economic, risk or time series analysis Generally chosen to suit the specific road safety research question Not used at strategic level
5. Process models To understand activities and operations	Used to develop and prioritise countermeasures: identify and assess potential risks and causes to develop and assess countermeasures	Allows understanding of sequences of and relationships between activities Facilitates identification of specific hazards and countermeasures Likely to be holistic, focus on purpose and consider relationships and components Likely to cover human resources and structural aspects	Implicitly describes components Difficult to apply to situations with many components since the process becomes too complex to analyse May not describe all outcomes May not to cover political or symbolic aspects	Can be used for very specific driving tasks Otherwise difficult to apply due to the complexity of the driving tasks and the complexity of wider transport system as a whole Not used at strategic level

Table 4 (*Continued*)

Model type and purpose	Model use	Strengths	Weaknesses	Relevance to road safety application
6. Safety management models For management of causes and risks, and development of countermeasures	Used for management assessments: organisation, procedures, resourcing, reporting	Frequently includes or is based on safety culture Non-specific, generally applicable to many situations or contexts Strong holistic focus on purpose and components Likely to cover human resources aspects Strong structural and human resource focus Can describe political and symbolic aspects	May not identify all causes, particularly outside the core system, or due to interactions Unlikely to consider all relationships Can be difficult to identify all opportunities for countermeasures May requires management commitment or legal basis (as in OHS) Relies on subsequent specific issues and countermeasures to be identified and assessed Provides little guidance to individual activities, processes, situations, contexts	Not evidently used Potentially applicable
7. System models To understand and develop system operation	Used to analyse systems including effects of countermeasures, influences and consequences	Facilitates an understand of the whole and contribution of components to purpose Focusses on holistic outcomes and changes Can encompass structural, human resources, political and symbolic topics Recognises interdependencies for consideration of all possible effects of any changes either in isolation, on other elements or together as complements May be supported by principles and/or a theoretical basis Should recognise structural, human resource, political and symbolic aspects as necessary	Can easily be too complex to be useful due to a multitude of relationships and components Difficult to apply to situations with many components since the process becomes too complex to analyse May not describe all outcomes Difficult to analyse and provide a strongly quantitative evidence basis	Descriptive models occasionally developed Detailed analytical models typically include statistical analysis, epidemiological, economic, or time series analysis can be used Currently used models are simple, not yet thoroughly based in theory and practice

identified that different models are not exclusive and exhibit characteristics evident in other model types. This is especially true for system models, which particularly include characteristics of component and sequence models. Different types of models may be more or less valuable depending on the circumstances to which they are applied. Safety management systems and the associated standards give good guidance for management, although they gave little assistance in describing and understanding the system under consideration itself. The most comprehensive descriptions relevant to understanding safety models were the management oversight and risk tree (MORT) descriptions, which were more of a toolbox of various concepts to be selected and used, depending on the needs and therefore incorporated several different model types.

4. Discussion

4.1. Relevance of alternative models to road safety

There were a variety of model types which have the potential to improve road safety, but are not yet applied. Probably all of the models identified in this review have the potential to be adapted to road safety and indeed, several have been used. Transport is characterised by thousands of components, operating relatively independently, but in close relationship over a period of time. Therefore, a variety of models may be applicable to road safety depending on the specific purpose to which it is used, and its context.

None of systems theory, safety management systems, the risk management approach, or safety culture was commonly or thoroughly applied to road safety, so application of these approaches may improve road safety strategies. The systems approach has the advantage of potentially including all relevant factors, components, contributors and outcomes, if thoroughly applied. Systems theory and systems approaches provide the opportunity to contribute to further improvements to efficiency and effectiveness of safety strategies.

Other safety domains, covering other modes of transport, took a wider perspective than road safety, recognising more contributing elements to safety, such as organisational culture, emergency responses, the health system and economic factors and influences (McInerney, 2005; Standards Australia, 2006a,b). Economic and social factors have long been recognised as being important considerations for the road safety context (Gordon, 1949; Haddon, 1973), but are often omitted. While supporting the current models of road safety policy, a broadening in thinking to a holistic view has been argued, by challenging social paradigms that were typically taken for granted in road safety policy (e.g., May et al., 2010). Other models described principles such as accidents being viewed as an ecologic problem (Gordon, 1949) or accidents being avoidable events and a result of human error (Heinrich et al., 1980). Many models took a narrow view of the accident causation based on the specific situation or task such as the human–machine–environment model (Wang et al., 2010). Mathematical models focussed on very specific or singular details, ignoring the wider context and interactions with other parts of the system. Therefore these alternative and sometimes complementary approaches may also have application to road safety.

Systems approaches and models have been successfully applied to several other safety domains, including transport, and to specific situations in road safety (Larsson et al., 2010; Salmon et al., 2012; Goh and Love, 2012; Read et al., 2013). While a systems approach has been claimed to be applied to road safety strategy (Wegman et al., 1995; Australian Transport Council, 2004; OECD, 2008), it has not been found in this study to have been applied thoroughly according to its theoretical foundation and practice elsewhere. The term ‘system’ was commonly, but casually, used in the road safety literature, without clear basis or definition. Models based on systems theory were characterised by individual units and their interrelationships, such as energy, information, etc. Relevant aspects of systems theory included definitions, specification, the nature of interrelationship and hierarchy. While 'system' is a fundamental concept in other safety domains, it has not been found in this study to have been soundly based or rigorously applied to road safety strategy and its use therefore offers potential to reduce road trauma.

Road safety strategies are often written with a government road safety perspective in mind. However, there are many other contexts and situations for which road safety and models are valid, including government non-transport agencies (e.g., treasury or education), private companies (particularly transport companies and those undertaking significant travel), the general public, NGOs and interest groups and service organisations. Application of these models is appropriate beyond government, despite it being held primarily responsible, which in itself is a contradiction of systems theory.

4.2. Categorisation of models

4.2.1. Systems theory and safety models

The term 'system' was commonly and often casually used in the literature without clear basis or definition. The literature highlights the need for distinction between terms including system, systems theory, systems approaches and system models. System models are primarily based on components, interrelationships, purpose, and interdependency, which other types of model may also describe in some way, although without the same theoretical basis or clarity. However, the generic term system is often used without definition and the specific system under consideration, and more specifically the boundaries of the system, is also often not clearly defined. Systems approaches (as described by principles, characteristics and processes) represent a way of thinking to analyse and improve systems.

4.2.2. Types of model

Seven different types of safety models were identified covering most of those described in the literature. Several models included human aspects (operator or user), infrastructure (or equipment), process (flow of work), the contextual environment (of widely varying types) and management. Models were based on a variety of perspectives, such as causes of accidents, or errors, leading to different elements being used in the descriptions to suit. Within model types there was diversity as to their content, with similar models found to include different details or applied in different contexts. Despite the hundreds of references and considerable variety, some models were more commonly used, with many referring to seminal work by Haddon (1968), Rasmussen (1980), Heinrich et al. (1980), Johnson (1980) and Reason (1990), further presented in Appendix A.

As mentioned, the language of strategy, modelling and safety was either poorly defined or poorly used. Terms such as safety, risk, hazard, and accident were often used interchangeably, whether or not they had specific definitions. Strategy could refer to a whole group of activities to achieve a widely based outcome (Wegman et al., 1995), or to a single activity (Rasmussen, 1980), a single situation (Wallis and Dovey, 2011), a single mechanism (Carayon et al., 2006) or a single outcome (Classen et al., 2007). The term strategy commonly related to a general direction of activity, whereas tactic or countermeasure tended to relate more often to specific interventions. Although the terminology is not universal, the terms model and system commonly appeared in our review, and can be applied to other activities besides strategy, including policy, planning, design, evaluation or other activities conducted to improve safety. However, the vague and diverse nature of the language used for models made analysis and understanding difficult.

4.2.3. Model diversity

The literature revealed models displaying diversity of size, complexity, maturity and sophistication, which were useful descriptors of systems, but one does not imply any of the others to any degree. For instance, a small system may be complex and an immature system may be sophisticated. A typical challenge for modelling is over-simplification which can improve ease of understanding, but result in loss of information or confusion. More extensive models are more thorough, but more difficult to understand. Even within one model type, there were many details which were not consistently described amongst all models of the type, so that a complete, simple and rational description was often not evident.

The evolution in refinement of models over time is evident. At the same time, contexts and systems also change requiring new models. For instance, Pun and Hui (2002) observed a move towards self-regulation reflected in UK, European, Australian and ISO standards. As the frequency of aircraft crashes increased as airline travel grew (Du and Liu, 2009), safety management systems, models and analysis were improved. Over time, models continue to develop and be devised to meet new challenges or represent alternative useful perspectives.

4.3. Purpose and value of different models and approaches

4.3.1. Purposes of models

Well-constructed models are best used to contribute to the ultimate purpose, in this case to improve safety efficiently and effectively. Ideally, models should be useful (informs and efficiently assists the reader practically); be adequate (complete and sufficient); be rational (logical, structured, coherent and reasonable), and be understandable (as simple as possible) (Kjellén and Larsson, 1981; Hayden, 2006). Models inherently have inaccuracies due to over-simplification and often depend on specific language.

It is important that any model is relevant and useful (Hayden, 2006). This review was limited to strategy and policy at the macro level defined as "*. . .consistencies, in the form and content of lower order systems (micro-, meso-, and exo-) that exist, or could exist, at the level of the subculture or the culture as a whole along with any belief system or ideology underlying such consistencies*" (Bronfenbrenner, 1979, p. 26). Therefore the models reviewed were at a high level to understand:

- alternatives and facilitate choices;
- all outcomes (other beneficial outcomes) and conflicts (undesired adverse outcomes); and
- synergies (complementary outcomes when activities occur at the same time).

Since most, or all, of the models presented have some acceptance in practice, it is likely that each of them may be useful depending on the context and the needs of the user. Many models may be reasonable, but were not clearly based in theory or practice. It is also not evident that any type of model is necessarily more valuable than others. Models appear to be originally developed based on an individual's perspective, although many have apparently been tested and developed satisfactorily in practice over time, such as those of Haddon (1968), Heinrich et al. (1980), and Reason (1990). Unfortunately, the comparative value of different types of model, or applicability to specific situations has not been tested in the present study or the literature, and offers the opportunity for further consideration to improve the application of models.

4.3.2. Advantages of different safety models

There are few examples of where different types of models are compared. It was not clear that any one particular type of model was most appropriate or more valuable, except perhaps for the narrow purpose for which it was employed. System models are most likely to be comprehensive covering the most important information and topics, but also importantly describing interrelationships and interdependencies. Mathematical models offer the most robust evidence base for quantitative analysis of consequences. However, while mathematical models provide a strong evidence base for very specific or singular issues of detail they tend to ignore the wider context and interactions with other parts of the system.

Models were described independently of other models and did not refer to other types in terms of value, comparative benefits or weakness. It was not evident that models of a specific type were generally suitable for a variety of other purposes for which they may be employed. Different models exist for different purposes, to suit different contexts or based on different theories. For this reason, a single comprehensive universally applicable model for all situations was probably unlikely to be devised. Alternative models covered different types of components, systems or processes, or provided additional information, which may potentially be applied in road safety. Despite the potential benefit of using a model from one field to another, some models from other fields have not been applied road safety.

Strategies are developed to make improvements to situations, by addressing a perceived problem. Road safety strategies focus on road users, vehicles, roads, and socio economic factors (Haddon, 1980; Leveson, 2004) to reduce crashes. However, safety strategies exist in many other fields as well, such as in occupational health (Rasmussen, 1980) and in hazardous industries (Johnson, 1980). Strategies also exist in other modes of transport (Gibson, 1961; Helmreich and Merritt, 1998) to improve safety. The information from these alternative perspectives has the potential to be transferred to further improve safety in different domains.

Activities and systems do not occur or exist in isolation, so strategies and models must consider the wider environment. The transport environment is diverse and includes community, technology, funding limitations, different levels of government, and other aspects (Hughes, 2010). A model for analytical purposes may be quite different to a model for strategy used to illustrate, summarise or 'sell' policy activities. For instance, strategies need to be targeted, since not all issues can be addressed at any point in time. So, it is entirely appropriate that strategies omit some, or many, issues. At the same time, unless the development of strategies is open to all the issues and opportunities there is a risk that the policies included will be sub-optimal.

5. Conclusions for road safety

Application of safety models from other domains should be investigated for use in road safety strategy. The investigation should be framed in terms of applicability to the situation and utility in achieving the intended outcomes. In particular, application of systems theory, safety management systems, the risk management approach, and safety culture models should be investigated to determine their utility in improving road safety.

System models and systems approaches have been successfully applied in other safety domains, including transport, providing the most thorough and comprehensive understanding of safety. Systems theory and systems approaches should be thoroughly applied in road safety research and practice at all levels, but particularly at the whole of system or strategic level. This result is consistent with Read et al. (2013, p. 773) who concluded for specific cases: "*The existing research has not applied a systems approach, and thus has not identified, described or explained emergent phenomena, variability in system functioning, dynamic aspects of the system and how influences at different system levels interact.*"

Techniques based on systems theory and the systems approach provide a more holistic and comprehensive understanding of a wider range of components and their interaction to influence the desired outcome. Previous conclusions regarding the use of terms according to systems theory and systems approaches were found to occur in road safety, "*the term 'systems' is being used rhetorically and one might conjecture, inappropriately*" (Waterson, 2009, p. 1192). Again, consistent with Read et al. (2013) systems theory and practices should be thoroughly applied to develop measures to improve road safety as a whole, which are more efficient and effective, especially in association with other complementary measures, rather than in isolation. As indicated, applying systems concepts techniques which provide a deeper understanding of how dynamic, complex system behaviour contributes to crashes (Underwood and Waterson, 2013b) would be expected to result in better road safety outcomes.

Models from other domains which include a wider context and greater breadth of factors affecting safety should be applied to improve road safety. Additional factors should be investigated, such as the effect of organisational culture, emergency responses, the health system and economic influences on road safety. In the context of road safety strategy development, analysis of road crashes at all levels should be broadened from a narrow view of causation based on the specific situation, task or crashes and direct contributing factors to take the wider contextual factors into account. There are theories, information and practices which can yet be applied with the potential to improve road safety at the strategic level.

Appendix A.

Origin	Type	Key elements and description
Gordon (1949)	Epidemiological	*Principles*: causative factors are in the host, agent and environment. The mechanism of accident production is the process by which the three components interact to produce a result, the accident; it is not the cause of the accident *Host*: age, sex, race, genetic inherent susceptibility *Agent*: physical, chemical, biological (not the mechanism) *Environment*: physical, biological, socioeconomic
Gibson (1961)	Accidents as an ecologic and psychological problem	*Environments*: terrestrial, geographic, natural and artificial *Classification of dangers*: mechanical energy (active impact, passive impact, interference with breathing, tool and machine forces, machine failures, animal forces, weapon produced forces), thermal energy (heat and cold), radiant energy (heat, ultraviolet, atomic), chemical (poisons), electrical energy (natural or man transmitted) *Margins of safety*: temporal and physical (barriers, gaps, and other protections) *Reasons*: misperception of danger, inappropriate reaction, motivation
Blake (1963)	Causes of accidents	*Accident factors*: contributors to industrial risks *Agency*: machines, moving equipment, boilers and pressure vessels, vehicles, animals, power transmission equipment, electrical equipment, hand tools, chemicals, inflammables and hot substances, dusts, radiations, working surfaces *Agency part*: specific individual parts of agencies *Unsafe condition*: inadequate guard, defect, hazardous arrangement or procedure, poor lighting or ventilation, unsafe dress or apparel, etc. *Accident type*: physical striking, being caught, fall, slip, exposure, inhalation, absorption, ingestion, electrical contact, etc. *Unsafe act*: operation without authority, improper operation, disabling safety devices, unsafe position, distraction/teasing/abusing/startling, failure to use protection, etc. *Unsafe personal factor*: improper attitude, lack of knowledge or skill, physical defect or weakness, etc.
Nader (1965)	Components	*Components*: engineering, enforcement, education
Haddon (1968, 1972)	Components and phases	*Components*: drivers, passengers, pedestrians, bicyclists, motor-cyclists, vehicles, highways, police, and 'many more specific issues'. *Factors*: human, vehicle & equipment, cargo, environment *Phases*: precrash, crash, postcrash
Fell (1976)	Driver/vehicle/environment information flow	Ambience, highway, vehicle, speed and directory, other road users Ambient information restrictions Vehicle information restrictions Aids to observations Driver: perception, comprehension, decision, action Guidance, vehicle controls, auxiliary Communication to others
Glass et al. (1979)	Safe system of work	Legal interpretation of definition used in legislation. The ordinary or usual method of carrying out the operation in which an employee is engaged. Specific systems vary but generally include process arrangement, operational steps, co-ordination of the operation, methods of use of equipment and process, supply of equipment and manpower, proper instructions, warnings and notices.
Haddon (1980)	Factors, phases and results	*Factors*: human, vehicles & equipment, physical environment, socio-economic environment *Phases*: pre-crash, crash, post-crash *Results*: damage to people, damage to vehicles & equipment, damage to physical environment, damage to society
Rasmussen (1980)	Human in a control system	*Process plant*: physical processes, mechanical, electrical, chemical *Control system*: symbolic processes *Operator*: information processes, goals & intentions, models & strategies, performance criteria *Relationships*: instructions, information, actions
Heinrich et al. (1980)	Steps of accident prevention	Basic philosophy of accident occurrence and prevention: attitude ability, knowledge, the desire to serve (humanity, industry, country) *Organisation, fact finding, analysis, selection of remedy, application of remedy*
Heinrich et al. (1980)	Sequence of factors (domino model)	*Social environment/ancestry, fault of person, unsafe act (mechanical or physical/hazard, accident, injury*
Heinrich et al. (1980)	Accident sequence after Bird	*Lack of control/management, basic causes/origins, immediate cause/symptom, accident/contact, injury-damage/loss*
Heinrich et al. (1980)	Accidents causation after Adams	*Management structure*: (objectives, organisation, operations), operational errors (manager behaviour, supervisor behaviour) *Tactical errors*: (employee behaviour, work conditions) *Accident incident*: injury producing, the near-miss no injury incident, the property damage incident, injury or damage (to persons, to properly)
Johnson (1980)	Management oversight and risk tree (MORT)	*Risk management:* system definition, risk identification, risk evaluation, risk reduction *Levels of relationship:* generic events (problems), basic events (causes), criteria (judgement rationale for adequacy) *Functions to complete a process* *Steps to fulfil a function* *Judgement criteria to judge adequacy*

Appendix A (*Continued*)

Origin	Type	Key elements and description
Johnson (1980)	Management oversight and risk tree (MORT)	*Management policy and implementation* *Hazard analysis process with risk evaluation* *Operations readiness:* preparation, test and qualification of physical elements, procedures and managerial controls and personnel *Operations & supervision* *Human performance*
Johnson (1980)	System definition in project risk analysis model	*System components*: plant and equipment, materials, energies, controls, human factors, operations/processes/procedures and environment With: performance and risk criteria, delineation of probable and potential changes, establishment of life cycle plan and numbers And: regulations, standards & recommendations
Johnson (1980)	Dynamics of home accidents	*Background factors:* persons (training experience, judgement), home (dwelling, yard, etc.), accident susceptibility, accident potential *Initiating factors*: change in patter, agent of accident *Intermediate factors*: physiological & mental factors, no recognition of danger, environmental factors, "makeshifts" *Immediate factors* *Measurable results*: mitigating factors, personal injury, property damage, no injury ort damage, "near accident" *Intervention*: another person, safety awareness, automatic cutoffs *Return to normal procedure* *Accident sequence*: patterns of operation (behaviour), person/day/activity, increase in susceptibility or potential, increase in hazard, unsafe act (trigger mechanism), agent of injury or damage
Booth (1980)	Police approach to road safety	*Engineering* *Education* *Enforcement:* information, organisation, vehicles, driver characteristics, arrests, patrols, selective enforcement, strategy
Rasmussen (1982)	Human malfunction in industrial installations	*Performance shaping factors:* subjective goals & intentions, mental load & resources, affective factors *Situational factors*: task characteristics, physical environment, work time characteristics *Causes of human malfunction:* external events, excessive task demand, operator incapacitated, intrinsic human variability *Mechanisms of human malfunction*: discrimination, input information processing, recall, inference, physical coordination *Internal human malfunction*: detection, identification, decision, action *Personnel task*: equipment design, procedure design, fabrication, installation, inspection, operation, test & calibration, maintenance & repair, logistics, administration, management *External mode of malfunction*: specific task not performed, erroneous act, extraneous act, sneak path or accidental timing of several events or faults
Perrow (1984)	'Normal Accident' definitions	*Systems*: for levels – units, parts, subsystems, system *Incidents*: cause damage to or failures of units or parts and hence failure of the whole system *Accidents*: involve damage to subsystems or the system as a whole causing the system to be stopped promptly *Component failure accidents* (units, part or subsystem): linked in anticipated sequences *System accidents*: unanticipated interaction of multiple failure *Policy recommendations*, depend on potential level of catastrophe and cost of countermeasure: abandon, restrict, tolerate & improve
Poole (1986)	Framework for comparative analysis of industrial relations	*Environmental conditions*: 1. Subjective meanings & policies – sociocultural values, political ideologies, economic policies, public and legal policies, 2. Structures – social, economic, political, technological, legal, demographic *Organisational structures & processes*: management policies, management styles *Industrial relations systems*: extent of shared decision making *Outcomes*
Grey et al. (1987)	Human factors for work design	*People factors: people, equipment and machines, personal workspace, wider workspace, physical environment, work organisation and job design* *Environment: financial, technical, legal, social*
Kasperson et al. (1988)	Hazard chain	*Human needs, Human wants, Choice of technology, Initiating event, Release, Exposure, Consequences*
Donegan et al. (1989)	Fire safety model	*Policy* – fire safety *Objectives* – life safety, property protection *Tactics* – ignition prevention, fire control, safe egress, rescue *Components* – occupants, doors, communications, internal planning, travel distance, flues/ducts
Reason (1990)	Accident cause, human error	*Principles*: humans are the source of all system problems, but not simply at the operator level. Other failures occur during any phase of the process or system including planning, design, constructions and maintenance. *Dimensions*: type of activity, focus of attention, control mode, predictability of error types, ratio of error to opportunity for error, influence of situational factors, ease of detection, relationship to change *Errors*: skill based, rule based or knowledge based *Production system components*: decision makers, line management, preconditions productive activities, defences *Contributions to failure*: fallible decisions, line management deficiencies, unsafe acts, inadequate defences *Unsafe acts*: slips, lapses, mistakes, violations (normal, exceptional)

Appendix A (*Continued*)

Origin	Type	Key elements and description
Sauter et al. (1990)	Psychological disorder prevention strategy categories	Job design to improve working conditions, surveillance of psychological disorders and risk factors, information dissemination, education, and training; enrichment of psychological health services for workers.
Embrey (1992)	MACHINE (Model of Accident Causation using Hierarchical Influence NEtwork)	*Human errors:* active, latent, recovery *Hardware failures*: human induced, random *External events* *Causal influences*: training, procedures, supervision, definition of responsibilities, demand/resource matching, production/safety trade-offs *Causal influences (policy)*: operational feedback, human resource management, risk management, design, communications system
Cameron (1992)	Road trauma chain	*Pre-crash*: entities exist (humans, vehicles, roads), entities eligible for road use (licensed registered roads opened), road use (distance, time), energy build up (speed, mass), exposure to crashes, crash involvement *Crash and post-crash*: crash involvement, energy dissipation, energy transfer, injury, sever injury, death *Risks*: public health, transport, injury, severe injury, fatal injury
Childers and Rohrer (1992)	Hazard Analysis and Critical Control Points (HACCP)	Identification and assessment of hazards Determine critical control points (CCPs) to control any identifiable hazards Establish critical limits to be met Establish CCPs monitoring procedures Establish corrective actions for deviations Establish effective record-keeping system Establish HACCP system verification procedures
Rothenberg (1993)	Based on Wildavsky's (1989) principles	*Principle of uncertainty*: irreducible uncertainty is universal *The axiom of connectedness*: good and bad are intertwined in the same acts and objects *The rule of sacrifice*: the safety or macro-stability of the whole is dependent upon the risk or instability of the parts
Cox and Cox (1996)	Integrated approach to safety systems	*Hardware:* technological & physical environment *Software*: management & work systems & procedures *People systems*: person, organisation, job
Rahimi (1995)	Strategic safety management (SSM)	*Culture change, long range planning, empowerment, leadership*
Stang (1996)	System approach to investigation	*Human–machine system*: interactive and tightly coupled parts, the proper functioning of the whole depends on the proper functioning of the parts, the proper functioning of the parts depends on the functioning of the whole. Complex technology is prone to multiple failure sequences. The failure of a part may interact with other parts and lead to failure of the system as a whole. Multiple failure possibilities are an inherent and normal system characteristic. There are possible multiple failure sequences, that cannot be predicted on either design or operating levels. Some result from unplanned, unexpected interactions between parts of the system (complex interactions). The human operator is a system component that intervenes at the critical moment. Human failures are component failures, which may enter into complex interactions with other components. Human failures are part of a multiple failure sequence. There are some rare complex interaction sequences that will bring the system to a halt and eventually destroy it. High energy concentrations mean risk of system destruction and catastrophe for the system's environment.
Liu and McDermid (1996)	Relationships to describe a physical system for fault tree analysis	*Physical Connection relation* *Logical Connection (relation)* *Contain (relation)* *Control (relation)* *Input relation (materials or information)* *Output relation (materials or information)* *Get-Information-From (relation)* *Process relation (process materials or information)* *Other relations*
Weinstein (1996)	Total quality management (TQM) applied to safety	*Basic TQM concepts*: product/customer focus, leadership and commitment, company culture, effective communication, employee knowledge, employee empowerment, responsibility and excellence, management by fact, long-range view *TQM techniques*: statistical process control, structured problem solving, best techniques, continuous improvement, quality management, quality planning *Steps to installing TQM*: assessment & planning, implementation & organisation, cultural change, recognition & reward systems, leadership development, team building, hiring & promoting practices, management readiness, statistical & analysis techniques, training *ISO 9000 quality programme requirements*: management responsibility, quality system, contracts review, design control, document & data control, purchasing, customer supplied product, product identification & traceability, process control, inspection & testing, equipment inspection measurement & testing, inspection & test status, control of nonconforming product, corrective & preventative action, handling, storage packaging preservation & delivery, control of quality records, internal quality audits, training, servicing, statistical techniques

Appendix A (*Continued*)

Origin	Type	Key elements and description
Rasmussen (1997)	Socio-technical system	*Stages*: government, regulators & associations, company, management, staff, work *Environmental stressors:* political climate & public awareness, market conditions & financial pressure, competency & education, technology *Disciplines*: political science, law, economics, sociology, decision theory, organisational psychology, industrial engineering, management & organisation, psychology, human factors, human–machine interaction, engineering (mechanical, chemical and electrical)
Glendon and Waring (1997)	Occupational safety management	*Risk*: pure, speculative *Objects*: hazards, threats *Objectives*: eliminate, reduce, control, enhance utility/benefit, reduce/eliminate detriment *Contexts*: inner, outer, change *Methods*: management system, risk management
Ansari and Modarress (1997)	Aircraft manufacturing industry safety strategy	*Executive leadership*: change culture, create high standards, democratic commitment *Training*: leadership, community, management, employees, accident investigation *Communications*: coordinate communications plan, communicate leadership commitment *Safety improvement processes*: implement safe work practices, implements practices, improve shop floor safety processes *Alternative work programme/return-to-work*: accommodate injured employees
Redinger and Levine (1998)	Summary of occupational heath safety management systems	*Management commitment and resources, employee participation, occupational health and safety policy, goals and objectives, performance measures, system planning and development, OHSMS manual and procedures, training system, hazard control system, preventive and corrective action system, procurement and contracting, communication system, evaluation system, continual improvement, integration, management review*
Redinger and Levine (1998)	OHS management system assessment components	*OHSMS principles* *Measurement criteria for each principle* *Suggested measures for each measurement criterion* *Data collection mechanisms* *Scoring/ranking scheme* *Methods for score/rank interpretation*
Redinger and Levine (1998)	OHS management system assessment instrument structure	*External environment*: stakeholders, regulating agencies/units *Open system elements*: continual improvement, integration, management review *Evaluation (OHS feedback)*: communication system, evaluation system *Initiation (OHS inputs)*: management commitment & resources, employee participation *OHS process*: formulation – OHS policy, goals & objectives, performance measures, system planning/development, manual & procedures Implementation/operations – training system, hazard control system, prevent/correct actions, procurement/contractors *OHS outputs*: OHS goals & objectives, illness & injury rates, workforce health, changes in efficiency, overall organisational performance
Harrald et al. (1998)	Model the impact of human error in a maritime system	*Stages*: root cause, immediate cause, incident, accident, consequences, impact *Risk reduction/prevention*: reduce frequency, reduce exposure, prevent accident, reduce consequences, reduce impact
Helmreich and Merritt (1998)	Aviation crew management – Crew performance model	*Crew performance input factors*: individual aptitudes, physical condition, crew composition, regulatory environment, operating environment, professional culture, organisational culture, national culture *Crew and mission performance functions*: crew formation & management, aircraft flight control, communications, decision processes, situational awareness, operating procedures *Mission and crew performance outcomes*: safety, efficiency *Individual and organisational outcomes*: attitude, morale
Helmreich and Merritt (1998)	Aviation crew management – errors and defenses Cultures and outcomes	*Air traffic control, workload, fatigue, complacency, maintenance* *Crew behaviour*: positive or negative – professional culture, national culture, training, organisational culture, safety culture, safe behaviour
Loader and Hobbs (1999)	Food safety regulation response adapted from French & Neighbours (1991)	*Compliance activity*: administrative, analytical, production formulation, packaging formulation, marketing, monitoring, information management *Compliance strategies*: production & operations, information technology, marketing, distribution, supply chain. *Regulatory responses*: stone-walling (doing as little as possible), opportunity seeking (to gain relative competitive advantage), mixed (new product development and marketing)
Hawksley (1999)	Major accident prevention policy (MAPP), EU directive	*Organisation and personnel, identification and evaluation of major hazards, design of new installations, operational control, including management of change, training and management of personnel, emergency planning, performance monitoring and audit.*
Hawksley (1999)	ICI Group SHE Standards	*Safety, health and environment (SHE) commitment, management and resources, communication and consultation, training, materiel hazards, acquisitions and divestments, new plant, equipment and process design, modifications and changes, SHE assurance, systems of work, emergency planning, contractors and suppliers, environmental impact assessment, resource conservation, waste management, soil and groundwater protection, product stewardship, SHE performance and reporting, auditing*
Porter and Wettig (1999)	Safety management system, following EU directive	*Organisation and personnel, identification and evaluation of major accident hazards, operational control, management of change, planning for emergencies, monitoring performance, audit and review.*
Van Urk and De Vries (2000)	Sea shipping safety – risk management	*Problem definition* *Problem analysis*: exogenous influences, traffic, accident statistics, possible measures, expert opinion *Risk model*: present risk, future risk *Evaluation*: risk limits, perception, acceptance, financial consequences, risk reduction

Appendix A (*Continued*)

Origin	Type	Key elements and description
O'Hare (2000)	Taxonomy for aviation analysis based on Helmreich	*Hazards recognised, hazards unrecognised* *Global conditions*: policies, philosophy, procedures *Local precipitating conditions*: task demands, interface, resources *Local actions*: by frontline workers *Local level factors*: representation/interface (displays, controls, communication), task demands (complexity, coupling, dynamism, uncertainty/risk), operator resources (physiological, psychological, skills/knowledge, attitudes/motivation)
O'Hare (2000)	Ladder model of human information processing for aviation analysis, from Rasmussen	*Goal, strategy* *Diagnosis* *Procedure* *Action* *Information*
Bottelberghs (2000)	Risk management cycle	*Identification of risks* *Assessment of the identified risks* *Evaluation of risks on the basis of acceptability criteria* *Imposing risk-reducing measures* *Monitoring and maintaining the acceptable risk*
Standards Australia and Standards New Zealand (2001a,b)	Occupational health and safety management system	Part of the *overall management system* which includes: organisational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the OHS policy, and so managing the risks associated with the business of the organisation. *Continuous improvement process*: policy, planning, implementation, measurement and evaluation, management review.
Standards Australia and Standards New Zealand (2001a,b)	Occupational health and safety management system	Establish, implement and maintain documented procedures. For hazard identification, hazard/risk assessment and control of hazards/risks. For activities, products and services over which an organisation has control or influence. *Policy*: commitment integration & relevance, compliance, accountability, consultation, prevention
Suraji et al. (2001)	Construction accidents	*Distal factors*: constraints and responses creating conditions or situations in which accidents become more likely – physical & business environment, project conception constraints, project management constraints & responses, client responses, project design constraints & responses, construction management constraints & responses, subcontractor constraints & responses, operative constraints *Proximal factors*: inappropriate construction planning or control, inappropriate site condition, inappropriate operative action, inappropriate construction operation *Accident event*: undesired event, ultimate undesired event, undesired outcome
Herijgers et al. (2002)	School safety policy and strategy	*Inspections, school rules, evacuation plan, accident registration, safety report*
Pun and Hui (2002)	Safety-focused quality management (SQM)	*Dimensions of standards*: Purposes, emphasis, eligibility, participants, evaluation, orientation, mechanics *Elements*: management responsibility, quality system, control review, design control, document & data control, purchasing, customer-supplied product, product identification, process control, inspection & testing, inspection & measurement, inspection & test status, control of non-conforming product, corrective/preventive action, handling, storage & delivery, control of quality records, internal quality audits, training, servicing, statistical techniques
Pun and Hui (2002)	Procedural guideline – implementation sequence	*Define corporate vision and mission* *Commit to change and improvement* *Develop safety-focused quality management objectives, goals and strategies* *Establish steering committee* *Identify critical processes and success factors* *Promote cultural change and team works* *Provide education and training to employees* *Incorporate with quality and safety management requirements* *Integrate the total quality management concepts and principles* *Build an integrated quality management system with safety focus* *Measure results and benchmark achievements* *Standardise improved procedures and practices* *Reinforce good safety-focused quality management practices with recognition and rewards* *Achieve performance excellence through continuous improvement*
Beard and Santos-Reyes (2003)	Fire safety management system (FSMS) structural organisation	*Total environment*: safety future, local environment, production environment *Management system (FSMS)*: policy implementation, co-ordination, functional, development, policy
Wiegmann and Shappell (2003)	Human factors analysis and classification system (HFACS)	*Organisational influences*: resource management, organisational climate, organisational process *Unsafe supervision*: inadequate supervision, planned inappropriate actions, failed to correct problem, supervisory violations *Preconditions for unsafe acts*: Environmental factors (physical, technological), condition of operators (adverse physiological states, adverse mental states, physical/mental limitations), Personnel factors (crew resource management, personal readiness) *Unsafe acts*: Errors (decision, skill-based, perception), violations (routine, exceptional)
Vernez et al. (2003)	Petri nets theory based risk analysis and accident modelling	*Implicit cognitive model* – human: knowledge, skills, rules *Machine state space* – state changes and machines states: normal, degraded, operator actions, machine induced events, flow induced events *Flow description* – flow

Appendix A (*Continued*)

Origin	Type	Key elements and description
Leveson (2004)	Systems approach, classification of factors. STAMP (Systems-Theoretic Accident Modelling and Processes)	*Inadequate enforcement of constraints* – unidentified hazards; inappropriate, ineffective, or missing control actions *Inadequate execution of control action* – communication flaw, inadequate actuator operation, time lag *Inadequate or missing feedback* – not provided in system design, communication flaw, time lag, inadequate sensor operation *Primary characteristics*: 1. top-down systems thinking recognising safety as an emergent system property rather than a bottom-up, summation of reliable components and actions; 2. focus on the integrated socio-technical system as a whole and the relationships between the technical, organisational, and social aspects; 3. focus on providing ways to model, analyse, and design specific organisational safety structures
Lund and Aarø (2004)	Structure of safety systems	*Process factors*: attitudes and beliefs (person), social norms, safety culture (context) *Risk factors*: behaviour (person), physical and organisational environment (context) *Prevention measures*: behaviour modification, attitude modification (person), structural modification (context)
Australian Transport Council (2004)	The safe system framework	*Safer speeds, safer vehicles, safer roads and roadsides* Admittance to the system, understanding crashes and risk, education information supporting road users, enforcement of road rules Including alert and compliant road users and human tolerance to physical force
Ng and Chow (2005)	Airport terminal fire safety strategy	*Passive building construction, fire services installation, fire safety management, control of risk factors*
Mitropoulos et al. (2005)	Hazard-exposure-incident	*Exposures*: hazardous situations, efficient work behaviours affected by activity & context characteristics, unpredictability of task and conditions, efforts to control situations, production pressures, efforts to control behaviours *Incidents*: exposures, errors & changes in conditions affected by error inducing factors, error management Incident sand consequences (from exposures and incidents) affected by protective measures
Loo et al. (2005)	Organisational activities for road safety strategies	*Vision, objectives, targets, action plan, evaluation and monitoring, research and development, quantitative modelling, institutional framework, funding*
Nadzam et al. (2005)	Patient safety strategy framework	*A culture of safety, reporting of adverse events and error-prone processes, communication about safety issues, analysis of reported adverse events, process redesign, application of technology, new safety enhancement activities*
Teo et al. (2005)	Framework for managing construction safety	*Policy*: understanding and implementation of SMS, understanding and participation in OHSMS, understanding and implementation of permit-to-work system *Process*: quality of subcontractors, understanding and implementation of safety procedures, carrying out work in a safe manner, carrying out work in a professional manner, type and method of construction *Personnel*: managements attitude towards safety, supervisors and workers attitudes towards safety, contextual characteristics of workers *Incentive*: monetary incentives, nonmonetary incentives, disciplinary action
Hirasawa et al. (2005)	Road safety evaluation	*General*: scope of project, interaction between new and existent facilities, etc. *Road structure:* road classification, design speed and structure of cross-section, etc. *Intersection:* number and types of intersections, visibility, layout, traffic flow, etc. *Road surface*: coefficient of sliding friction, pavement defects, surface condition, etc. *Delineation facilities*: pavement markings, delineators, lighting, road signs, etc. *Physical objects*: median strips, safety barriers/fences/shields, recovery zones, etc. *Natural environment*: weather: short- & long-term, wild animals, etc. Road *users*: automobile, pedestrian, bicycle traffic; etc. *Access & adjacent*: Development: access roads, development plans along the route, etc. *Winter conditions*: road weather information, road maintenance operation, etc.
Carayon et al. (2006)	SEIPS – systems engineering initiative for patient safety	*Work system or structure*: person, organisation, technology & tools, tasks, environment *Process*: core processes, other processes *Outcomes*: employee & organisational, outcomes, patient outcomes
Morley and Harris (2006)	Safety culture model	*Layers of influences*: society, government (legislature/judiciary), regulator, senior management, middle management, line workers <ENUN>*Categories* <ENUN-P > concerns, influences, actions, failures
Nivolianitou et al. (2006)	Major accident reporting system (MARS), EU directive response	*Type of accident, industry where accident occurred, activity being carried out, components directly involved, causative factors (immediate and underlying), ecological systems affected, emergency measures taken*
Reniers et al. (2006)	Summary of risk assessment tools	*Range of risks covered*: operational, process, fire, explosion dispersion, toxicity, environmental, internal domino, external domino *Do the results support*: investment decisions, siting decisions, zoning and planning, planning decisions of emergency response services, actual disaster abatement, by real time calculations *Risk decision steps*: scope are and hazard type, rank installations, identify and prioritise risks, estimate risks, propose actions, prioritise work, simulate risk identification, quantitative risk assessment, prioritise further action
Bonita et al. (2006)	Epidemiological	*Causation:* genetic factors and environmental factors (including behaviours) affect good or ill health. Environmental factors include any biological, chemical, physical, psychological, economic or cultural factors that can affect health, *Natural history:* changes to health by subclinical changes and clinical disease result in death or recovery *Interventions*: Treatment, medical care, health promotion, preventative measures, public health services

Appendix A (*Continued*)

Origin	Type	Key elements and description
Capon (2006)	Framework for sustainability and population health	*Ecological footprint*: Economy & work, transport & urban form, housing & building construction, nature & landscape, media & communication, culture & spirituality *Human health and wellbeing*: air, water, noise, infection, chemical exposures & climate, food, activity, safety, family relationships, social capital
GAO (2006)	US Occupational Safety and Health Administration (OSHA) safety programme components	*Management commitment*: establish goals, communicate to staff, information systems, establish programme responsibilities of managers and employees, accountability *Employee involvement*: reporting job-related incidents and damage, reporting hazards, access to accidents and hazards system, involvement in safety committee, employee input on safety-related training curricula, walkthroughs of worksites to identify hazardous conditions, accident investigation teams. *Education and training*: general awareness training, specified group training, monitor training *Identification of hazards*: required inspections, informal walkthroughs of worksites. *Following up and correcting hazards*: develop controls for workplace hazards, follow up on inspections, automated workplace hazard monitoring. *Medical management*: employees seen within specified time frame, automated accident data monitoring, restricted or light duty return-to-work programme, automated return-to-work status of employees monitoring.
Dandona (2006)	Road safety strategy	*Category*: magnitude of crashes, causes of crashes, prevention of crashes, legislation related to road safety *Measures relate to*: drivers, vehicles, road, traffic law enforcement, emergency care, publicity, others
Attwood et al. (2006)	Accident model for oil and gas industry	*External elements*: value of life, price of oil, shareholder pressure, royalty regime *Corporate elements*: corporate safety culture, corporate training programme, safety procedures *Direct factors*: behaviour (attitude, motivation), physical capability (co-ordination, fitness, lack of fatigue), mental capability (knowledge, intelligence) *Weather* *Safety design* *Personal protective equipment*
Reniers et al. (2006)	Risk assessment decision framework, based on Dept. of Defense	*Severity of consequences*: catastrophe, critical, marginal, negligible *Hazard probability*: frequent, probable, occasional, remote, improbable, impossible *Risk code/actions*: unacceptable, undesirable, acceptable with controls, acceptable
Standards Australia (2006a,b)	Railway safety management, general requirements	*General safety management principles:* establishing effective risk management, ensuring that emergencies and other occurrences can be properly managed, ensuring that interfaces between different organisations and organisational elements, protection of passengers, rail safety workers and maintaining public health, safety and security, and protection of property from damage *Implementation*: operational aspects, infrastructure aspects, rolling stock aspects, interfaces with other transport modes, Interfaces with other rail networks, human factors management. *Safety management system (components)*: safety management policy; allocation of responsibility and accountabilities; risk management system (risk identification, evaluation, analysis and control, maintaining a risk register; risk mitigation through an action plan that includes resources); policy and procedures for safety documentation, information and data control; procedures for personnel management; procedures for goods and services procurement; procedures for all life cycle stages of asset management (design, construction, operation, maintenance, modification and eventual removal); procedures for interface management; change management methods and procedures; procedures for disseminating information within the organisation and between organisations; emergency management; occurrence notification, investigation, analysis, developing safety actions and reporting in a 'just culture' environment; key safety performance indicators and performance monitoring; management review and auditing; security management; safety culture development and maintenance.
Gunduz and Simsek (2007)	Balanced scorecard	*Framework* (goals & measures): customer perspectives, internal business, innovation & learning, financial *Perspectives:* financial & cultural, employee, process, learning
Classen et al. (2007)	Health promotion perspective	*Administrative & policy: health education, policy, regulation, organisation* *Educational and ecological assessment: predisposing factors, reinforcing factors, enabling factors* *Behavioural & environmental* *Epidemiological: health* *Social: quality of life*
Liou et al. (2008)	Factors of an aviation safety management system	*Communication, documentation, equipments, incident investigation and analysis, safety policy, rules and regulations, safety committee, safety culture, safety risk management, training and competency, work practice.*
Runyan and Yonas (2008)	Haddon model integrated with the social–ecologic framework (matrix)	*Phases*: precrash, crash, postcrash *Host factors* and *vehicle factors* *Relationship factors:* peers, parents *Physical and social environments factors:* institutions and organisations, sociocultural practices and norms
May et al. (2010)	Wellbeing paradigm	*Urban ecological impact:* economy & work, transport & urban form, housing & buildings, nature & landscape, media & communication *Human health and wellbeing:* air, water, noise, infection, chemical exposures, local climate, food access, physical activity, safety, family relationships, social capital
Zhou et al. (2008)	Safety climate factors	*Safety management systems and procedures, management commitments, safety attitudes, workmate's influences, employee's involvement*

Appendix A (*Continued*)

Origin	Type	Key elements and description
Bellamy et al. (2008)	Integrated functional model	*World of human factors, safety management, organisation* *Basic taxonomy* 1. Major hazards, onshore, chemical 2. Potential for accidents: hazards, triggers 3. Technical aspects: activities, technical measures 4. Organisation: complexity of design & process, external climate, organisational performance shaping factors (PSF's) 5. Safety management system: regulation specific (policy, organising, planning & implementing, measuring, audit & review) 6. Key risk control systems: design, operations, modifications, emergencies 7. Human factors: human factors PSF's, demands/stressors, capacities PSF's, psychological capabilities, anatomical capabilities, human behaviour outcomes Accident outcomes: fire toxic release, explosion *Warning themes*: safety management system, risk control, organisation, human factors *Task competencies*: delivery system, major accident prevention measures, selection & training, competence
Einarsson and Brynjarsson (2008)	Contributors	*Company*: organisational units, groups individuals *Institutions/Governmental bodies*: external actors, contractors, fire authority, *External*: workers environment authority, external environment authority *Risks*: physical, process, emotional, communications, group
Devine et al. (2008)	Framework for health promotion action – mining site	*Disease prevention, communication strategies, health education and empowerment* *Community and health development, infrastructure and systems changes*
McGraw et al. (2008)	Factors influencing clinical practice from Association of Litigation and Risk Management, based on Vincent et al. (1998)	*Institutional context*: economic and regulatory context, NHS executive, clinical negligence scheme for trusts, links with external organisations *Organisational and management factors*: financial resources and constraints, organisational structure, policy standards and goals, safety culture and priorities *Work environmental factors*: administration, building and design, environment, equipment/supplies, staffing, training, workload/hours of work, time factors *Team factors*: verbal and written communication, supervision and seeking help, congruence and consistency, leadership and responsibility, staff response to incidents *Individual (staff) factors*: knowledge and skills, competence, physical and mental health, *Task factors*: task design, availability and use of protocols, availability and accuracy of test results, decision-making aids *Patient factors*: condition, personal, treatment, history, staff–patient relationship
Makin and Winder (2008)	Occupational safety management	*External environment, physical workplace, people, management* *Safe place, safe person, safe system*
Makin and Winder (2008)	Occupational safety 'safe system'	*OHS policy, goal setting, accountability, due diligence review/gap analysis, resource allocation/administration, procurement, supply, competent supervision, safe working procedures, communication, consultation, legislative updates, procedural updates, record keeping/archives, customer service, self assessment tool, audits and system review*
May et al. (2010)	Social ecological model of road safety	*Road safety:* Community, well-being, slow movement, sustainable transport, access to local shops, schools, services, localism *Road crashes:* Individualism, consumerism, culture of speed, car/road dominance, closure of local shops schools & services, globalisation *Road safety enhancers:* Peak oil, climate change, foresight *Road safety inhibitors:* Cheap oil, road lobby, status quo
Sherman et al. (2009)	International classification for patient safety	*Actions taken to reduce risk influenced by and informing:* *Contributing factors/hazards* *Incident type: patient characteristics, incident characteristics* *Detection* *Mitigating factors* *Patient and organisational outcomes* *Ameliorating actions*
Burns and Machado (2009)	Actor-system dynamics (ASD)	*Social structures*: political, economic, and cultural rule regimes – administrative systems, markets, democratic forms, medical systems, universities *Socio-technical systems* *Physical & ecosystem structures*: time/space conditions, natural resources, opportunities, physical constraints, material payoffs *Agency*: social actors, interactions *Processes and outcomes generated*: production, distribution & exchange, innovation, deviance, power & control activities, socialisation & educational processes, conflict/competition, strategic structuring, modelling of physical & social systems, structural maintenance & reproduction *Influences*: structural reproduction/elaboration/transformation, social structuring & selection, natural structuring & selection, impacts
Whitefield (2009)	Safety management improvement	*Drivers* (inputs): 1. Knowledge of hazards, implementation of controls. 2. Identification of required management system elements, management systems model (AS/NZS4804), policies, procedures, instructions, forms, records. 3. Safety thinking mindset, leadership skills (leading safe behaviours, coaching safety thinking, rewarding positive behaviours). *Safety management*: 1. Safety control (reactive, direct costs, quick improvement). 2. Safety management (proactive, direct and indirect costs, step change improvement). 3. Safety leadership (empowering, indirect costs, continuous improvement). *Measurement activities* (outputs): 1. Workplace inspections. 2. Management systems audit. 3. Behavioural observation, safety attitude survey.
Du and Liu (2009)	Air freight transport	*Human–machine–environment (H–M–E)* *Employees, management, equipments and dangerous goods*

Appendix A (*Continued*)

Origin	Type	Key elements and description
Lundberg et al. (2009)	Various models	*Social*: organisational values, relationships, trust, individual background *Technological organisational*: control hierarchy, internal regulation, incident reporting, safety audit, maintenance *Human*: consequences, compliance *Safety culture information*: availability, communication, safety relevance *Economy vs. production*
Katsakiori et al. (2009)	Types of model for accident investigation	*Causation models*: systemic (e.g., management oversight and risk tree), human information processing (e.g., work accidents investigation technique), sequential (e.g., occupational accident research unit) *Stand-alone techniques*: tree techniques (e.g., fault tree analysis)
Finch et al. (2009)	Group safety themes in recreational facilities	*Users*: casual, members, special needs *Staff*: management, programme, administration *Other*: Owners/council, insurers, professional bodies
Cassano-Piche et al. (2009)	Structural hierarchy and Accimap	*Government* *Regulatory bodies* *Local government* *Technical & operational management* *Physical processes & actor activities* *Equipment & surroundings*
Wegman et al. (1995), OECD (2008), Holló et al. (2010)	Road safety management system	*Results*: social factors, final outcomes, intermediate outcomes, outputs *Interventions*: planning, design and operation of the road environment, entry and exit of vehicles and people to the road environment, recovery and rehabilitation of crash victims in the road environment *Institutional management functions*: results focus, coordination, legislation, funding and resource allocation, promotion, monitoring and evaluation, research and development and knowledge transfer
Runciman et al. (2010)	Operational ontology of patient safety	*Contributing factors and hazards*: environmental factors, organisational factors, human factors, subject of incident factors, drugs equipment & documentation *Failure or penetration of defences* *Incident*: could have or did lead to loss or harm, near miss or adverse event, incident details *Factors minimising or aggravating outcomes or consequences* *Outcomes and consequences*: healthcare outcome for patient, consequences for the organisation *Action taken*: immediate, subsequent, planned, resource impact *Overall outcome (actual or potential) and resources impact and risk taking*
Hsu et al. (2010)	Dimensions and components of safety management system based on five international aviation standards	*Organisation*: safety policy, safety objective and goals, organisational structure, responsibilities & accountabilities, management commitment, performance measurement/baseline *Documentation*: identification and maintenance of applicable regulations, documentation describing system component, records management, information management *Risk management*: investigation capability, hazard identification, safety analysis capability, risk assessment, recommending actions based on safety metrics *Quality assurance*: safety performance monitoring, audits, change management *Safety promotion*: training, safety culture, safety lessons learned, communication, proactive process *Emergency response*: emergency response plan, risk management capability, emergency proactive action
ACT Government (2010)	Strategic plan for road safety	*Strategic goals:* Road trauma rates continue to be reduced despite increases in population and travel. The community shares the responsibility for road safety. Road safety co-ordination and support are improved. *Strategic objectives*: Safer speeds. Safer roads and roadsides. Safer vehicles. Safer road users. Improved coordination and consultation processes. *Countermeasures*: education, encouragement, engineering, enforcement, support.
Wang et al. (2010)	Quantified risk assessment (QRA)	*Factors*: human, machine or environment related *Events*: desired/undesired faults errors, anomalies *System behaviour*: safe/unsafety behaviour, accidents, incidents
Wallis and Dovey (2011)	Modified Manchester patient safety framework	*Overall commitment to quality* *Priority given to patient safety* *Perceptions of the causes of patient safety incidents and their identification* *Investigating patient safety incidents* *Team learning following a patient safety incident* *Communication about safety issues* *Staff management and safety issues* *Staff education and training about safety issues* *Team working around safety issues*
Miller et al. (2011)	Patient safety	*Raise awareness and improve working knowledge*: educate, network, create a safety culture, expand focus *Act and advocate to minimise harm*: Error reporting, leadership, enhance family-centred care *Apply best practice*: Adhere to best practice, target drug safety, redesign clinical systems, support research
Newnam and Watson (2011)	Light vehicle fleet safety	Pre-crash, At scene, Post-crash *Strategies*: management culture, journey, road/site environment, people, vehicle, society/community, brand *Intervention level*: organisation, work group, individual *Intervention focus*: senior level management, workgroup supervisor/fleet manager, individual driver *Intervention target group*: e.g., Director/CEO, pooled vehicle drivers, salary sacrificed drivers *Intervention strategies*: risk management (e.g., policies, procedures, database, recruitment, induction), leadership training, discussion groups/feedback/goal setting

Appendix A (*Continued*)

Origin	Type	Key elements and description
Roelen et al. (2011)	Causal modelling of air transportation system (CATS)	*Event sequence diagrams* (ESD): initiating event, pivotal event, end event *Fault tree* (FT): base event, intermediate event, human error, top event *Bayesian belief network* (BBN): managerial influences, human error probability
Ball (2011)	Process system management	*Leadership involvement & responsibility, identification & compliance with legislation & industry standards, employee selection, placement & competency assurance, workforce involvement, communication with stakeholders, hazard identification & risk assessment, documentation, records & process knowledge management, operating manuals & procedures, process monitoring & operational status handover, management of operational interfaces, standards & practices, management of change & project management, operational readiness & process start-up, emergency preparedness, inspection & maintenance, management of safety critical devices, work control, permit to work & task risk management, contractor selection & management, incident reporting & investigation, audit, assurance and management review & intervention*
Black et al. (2011)	Safety case	*Process*: 1. Safety plan: roles and responsibilities of stakeholders 2. Safety properties requirements: based on standards and culture 3. Preliminary hazard analysis Risk estimation is then completed on the hazards *Requirements, Safety Management, Safety, Control Measures, Hazard* *Intent*: 1. Programme management – management view 2. System purpose – customer view 3. System design principles – system engineering view 4. System architecture – interface between systems and component engineers 5. Design representation – component designer view 6. Physical representation – component implementer view System operations – operations view Part – whole: Environment, operator, system, verification & validation
Jacinto et al. (2011)	Occupational accident reporting framework – ESAW (European statistics of accidents at work)	*Working environment*: workplace, work premises or general environment *Working process*: main type of work, task (general activity) being performed *Specific physical activity*: activity being performed just before the accident *Material agent of the specific physical activity*: the main agent associated or linked to the specific physical activity just before the accident. *Deviation*: the last event deviating from normality and leading to the accident, the event that triggers the accident. *The material agent of the deviation*: the material agent associated with the deviation – the tool, object, or instrument involved in the abnormal event. *Contact mode of injury*: the contact that injured the victim describes how the person was hurt (physical or mental trauma). *Material agent of the contact*: the main material agent associated or linked to the injuring contact
Mullai and Paulsson (2011)	Contributing factors to marine accidents	*Time, location, ship's properties, ship/ship's activity, cargo, environmental conditions, cause, other, exposure, marine event, consequence*
Gaal et al. (2011)	Primary care health safety management	*Facilities in the practice, patient safety management, communication and collaboration, generic conditions for patient safety, education on patient safety*
NSTC (2010)	Environmental health and safety research strategy	*Product life stages*: raw materials, research design & development, production, commercialisation consumer use, disposal or recycling *Environmental pathways*: air, water, soil, wastewater, landfills *Transport and transformation*: environmental conditions, biological conditions, primary & secondary contaminants *Exposure (biota)*: aquatic, terrestrial *Exposure (human)*: inhalation, ingestion, dermal absorption Effects: ecosystems, humans
Department of Transport, Office of Rail Safety (DOT, 2011)	Comparison of rail safety management system content	*Safety policy; safety culture; governance & internal control arrangements; management, responsibilities, accountabilities and authorities; regulatory compliance; document control arrangements and information management; review of the safety management system; safety performance measures; safety audit arrangements; corrective action; management of change; consultation; internal communication; human factors; procurement and contract management; general engineering & operational systems safety requirements; process control; asset management; safety interface coordination; management of notifiable occurrences; rail safety worker competence; security management; emergency management; fatigue; drugs and alcohol; health and fitness; resource availability; independent investigations; codes of practice & guidelines (standards)*

References

ACT Government, (Discussion Paper) 2010. Vision Zero ACT Road Safety Strategy 2011–2020. Australian Capital Territory (ACT) Government, Canberra.

Ansari, A., Modarress, B., 1997. World-class strategies for safety: a Boeing approach. Int. J. Oper. Prod. Manage. 17 (3–4), 389–398.

Attwood, D., Khan, F., et al., 2006. Occupational accident models – where have we been and where are we going? J. Loss Prev. Process Ind. 19 (6), 664–682.

Australian Transport Council, 2004. National Road Safety Action Plan for 2005 and 2006. Commonwealth Department of Transport and Regional Services. Australian Transport Council, Canberra.

Ball, M., 2011. Energy Institute Framework for Process Safety Management. Process Safety 2010. Energy Institute, London.

Beard, A.N., Santos-Reyes, J., 2003. A safety management system model with application to fire safety offshore. Geneva Pap. Risk Insur. Issues Pract. 28 (3), 413–425.

Bellamy, L.J., Geyer, T.A.W., et al., 2008. Integrating human factors, safety management systems and wider organizational issues: a functional model. Loss Prev. Bull. 199, 18–24.

Benner, L., 1985. Rating accident models and investigation methodologies. J. Saf. Res. 16 (3), 105–126.

Black, D.D., Hull, M.E.C., et al., 2011. Systems engineering and safety – a framework. IET Softw. 5 (1), 43–53.

Blake, R.P., 1963. Industrial Safety. Prentice-Hall, Englewood Cliffs.

Bolman, L.G., Deal, T.E., 1984. Modern Approaches to Understanding and Managing Organizations. Jossey-Bass, San Francisco.

Bonita, R., Beaglehole, R., et al., 2006. Basic Epidemiology. World Health Organisation, Geneva.

Booth, W.L., 1980. Police Management of Traffic Accident Prevention Programs. Charles C Thomas, Springfield.

Bottelberghs, P.H., 2000. Risk analysis and safety policy developments in the Netherlands. J. Hazard. Mater. 71 (1–3), 59–84.

Bronfenbrenner, U., 1979. The Ecology of Human Development; Experiments by Nature and Design. Harvard University Press, Cambridge.

Burns, T.R., Machado, N., 2009. Technology, complexity, and risk: social systems analysis of risky socio-technical systems and the likelihood of accidents (Tecnología, complejidad, y riesgo: análisis social sistémico de sistemas sociotécnicos de riesgo y de la probabilidad de accidentes). Sociologia, Problemas e Práticas (61), 11–39.

Cameron, M., 1992. Accident Data Analysis to Develop Target Groups for Countermeasures. Monash University Accident Research Centre, Melbourne.

Capon, A., 2006. Submission No. 103 to House of Representatives Inquiry into a Sustainability Charter.

Carayon, P., Schoofs Hundt, A., et al., 2006. Work system design for patient safety: the SEIPS model. Qual. Saf. Health Care 15 (Suppl. 1), i50–i58.

Cassano-Piche, A.L., Vicente, K.J., et al., 2009. A test of Rasmussen's risk management framework in the food safety domain: BSE in the UK. Theor. Issues Ergon. Sci. 10 (4), 283–304.

Childers, A.B., Rohrer, S.L., 1992. A new food safety strategy for tropical America. Ann. N.Y. Acad. Sci. 653, 376–379.

Classen, S., Lopez, E.D.S., et al., 2007. Population-based health promotion perspective for older driver safety: conceptual framework to intervention plan. Clin. Interv. Aging 2 (4), 677–693.

Cochrane Reviews, 2011. In: Higgins, J., Green, S. (Eds.), Part 2: Searching for Studies. Cochrane Handbook for Systematic Reviews of Interventions. The Cochrane Collaboration (Updated March 2011).

Cox, S., Cox, T., 1996. Safety, Systems, and People. Butterworth-Heinemann, Oxford.

Dandona, R., 2006. Making road safety a public health concern for policy-makers in India. Natl. Med. J. India 19 (3), 126–133.

Dekker, S., Nyce, J., 2010. How can ergonomics influence design? Moving from research findings to future systems. Ergonomics 47 (15), 1624–1639.

Devine, S.G., Muller, R., et al., 2008. Using the Framework for Health Promotion Action to address staff perceptions of occupational health and safety at a fly-in/fly-out mine in north-west Queensland. Health Promot. J. Aust. 19 (3), 196–202.

Donegan, H.A., Shields, T.J., et al., 1989. A mathematical strategy to relate fire safety evaluation and fire safety policy formulation for buildings. In: 2nd International Symposium on Fire Safety Science Shobokaikan, Tokyo. Japan Hemisphere Publ. Corp..

DOT, 2011. Safety Management System Requirements Compared Between the Rail Safety Act 2010. Regulations 2011. AS4292. 1-2006, The National Accreditation Package (NAP) and National Model Rail Safety Legislation (NML). S. M. S. R. Comparison, Office of Rail Safety (ORS), Department of Transport (DOT), Government of Western Australia, 40.68KB.

Du, J., Liu, Z.,2009. Research on safety factors analysis and strategy of dangerous goods transportation by air. In: China–Japan Symposium on Safety Management Theory and Practice. Xian Univ. Sci. and Technol., Xian, People's Republic of China.

Einarsson, S., Brynjarsson, B., 2008. Improving human factors, incident and accident reporting and safety management systems in the Seveso industry. J. Loss Prev. Process Ind. 21 (5), 550–554.

Embrey, D.E., 1992. Incorporating management and organisational factors into probabilistic safety assessment. Reliab. Eng. Syst. Saf. 38 (1–2), 199–208.

Fell, J.C., 1976. A motor vehicle accident causal system: the human element. Hum. Factors 18 (1), 85–94.

Finch, C., Donaldson, A., et al., 2009. The safety policies and practices of community multi-purpose recreation facilities. Saf. Sci. 47 (10), 1346–1350.

Gaal, S., Verstappen, W., et al., 2011. What do primary care physicians and researchers consider the most important patient safety improvement strategies? BMC Health Serv. Res. 11, 102.

GAO, 2006. Workplace Safety and Health OSHA Could Improve Federal Agencies' Safety Programs With a More Strategic Approach to Its Oversight: GAO-06-379. GAO Reports. U.S. Government Accountability Office (GAO).

Gibson, J.J., 1961. The Contribution of Experimental Psychology to the Formulation of the Problem of Safety – A Brief for Basic Research. Behavioural Approaches to Accident Research. Assoc. for the Aid of Crippled Children, New York, pp. 77–89.

Glass, H.H., McHugh, M.H., et al., 1979. The Liability of Employers in Damages for Personal Injury. Law Book Co., Sydney.

Glendon, I., Waring, A., 1997. Risk management as a framework for occupational health and safety. J. Occup. Health Saf. Aust. N. Z. 13 (6), 525–532.

Goh, Y.M., Love, P.E.D., 2012. Methodological application of system dynamics for evaluating traffic safety policy. Saf. Sci. 50 (7), 1594–1605.

Gordon, J.E., 1949. The epidemiology of accidents. Am. J. Public Health 39, 504–515.

Grey, S.M., Norris, B.J., et al., 1987. Ergonomics in the Electronic Retail Environment. ICL (UK) Ltd, Slough, UK.

Gunduz, M., Simsek, B., 2007. A strategic safety management framework through balanced scorecard and quality function deployment. Can. J. Civ. Eng. 34 (5), 622–630.

Haddon, W., 1968. The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based. Am. J. Public Health 58, 1431–1438.

Haddon, W., 1972. A logical framework for categorizing highway safety phenomena and activity. J. Trauma 12 (3), 193–207.

Haddon, W., 1973. Energy damage and 10 countermeasure strategies. J. Trauma Inj. Infect. Crit. Care 13 (4), 321–331.

Haddon, W., 1980. Options for the prevention of motor vehicle crash injury. Isr. J. Med. Sci. 16 (1), 45–65.

Hale, A.R., Hovden, J., 1998. Management and culture: the third age of safety. A review of approaches to organisational aspects of safety, health and environment. In: Feyer, A.M., Williamson, A. (Eds.), Occupational Injury: Risk, Prevention and Intervention. Taylor & Francis, London.

Harrald, J.R., Mazzuchi, T.A., et al., 1998. Using system simulation to model the impact of human error in a maritime system. Saf. Sci. 30 (1–2), 235–247.

Hawksley, J.L., 1999. Developing a major accident prevention policy. J. Hazard. Mater. 65 (1–2), 109–121.

Hayden, F.G., 2006. Policy Making for a Good Society: The Social Fabric Matrix Approach to Policy Analysis and Program Evaluation. Springer, New York.

Heinrich, H.W., Petersen, D., et al., 1980. Industrial Accident Prevention. McGraw-Hill, New York.

Helmreich, R.L., Merritt, A.C., 1998. Culture at Work in Aviation and Medicine: National, Organizational, and Professional Influences. Ashgate, Aldershot, England/Brookfield, VT, USA.

Herijgers, C., van Eck, S., et al., 2002. 'Safety in primary schools: towards an accident-free school': national implementation of a safety-policy strategy at primary schools in The Netherlands. Inj. Control Saf. Promot. 9 (2), 133–135.

Hirasawa, M., Asano, M., et al., 2005. Study on designing and introduction of a road safety management system as a new road safety policy. In: 6th Conference of the Eastern Asia Society for Transportation Studies, Bangkok, Thailand.

Holló, P., Vojtech, E., et al., 2010. Road safety performance indicators and their explanatory value: a critical view based on the experience of Central European countries. Saf. Sci. 48, 1142–1150.

Hsu, Y.-L., Li, W.-C., et al., 2010. Structuring critical success factors of airline safety management system using a hybrid model. Transp. Res. E: Logist. Transp. Rev. 46 (2), 222–235.

Hughes, B.P., 2010. Railway challenges, realities and business opportunities. The business of Australia's railways. In: Proceedings from the Australian Railways Business and Economics Conference, Perth Australia, 20th July 2009. Wills-Johnson. Centre for Research in Applied Economics, Perth, Australia, pp. 38–64.

Jacinto, C., Soares, C.G., et al., 2011. An overview of occupational accidents notification systems within the enlarged EU. Work 39 (4), 369–378.

Johnson, W.G., 1980. MORT Safety Assurance Systems. National Safety Council and Marcel Dekker Inc.

Kasperson, R.E., Kasperson, J.X., et al., 1988. Corporate Management of Health and Safety Hazards. Westview Press, Boulder.

Katsakiori, P., Sakellaropoulos, G., et al., 2009. Towards an evaluation of accident investigation methods in terms of their alignment with accident causation models. Saf. Sci. 47 (7), 1007–1015.

Kjellén, U., 2000. Prevention of Accidents Through Experience Feedback. Taylor & Francis, London.

Kjellén, U., Larsson, T.J., 1981. Investigating accidents and reducing risks – a dynamic approach. J. Occup. Accid. 3 (2), 129–140.

Larsson, P., Dekker, S.W.A., et al., 2010. The need for a systems theory approach to road safety. Saf. Sci. 48 (9), 1167–1174.

Leveson, N., 2004. A new accident model for engineering safer systems. Saf. Sci. 42 (4), 237–270.

Leveson, N.G., 2011. Engineering a Safer World: Systems Thinking Applied to Safety. Massachusetts Institute of Technology, Cambridge.

Liou, J.J.H., Yen, L., et al., 2008. Building an effective safety management system for airlines. J. Air Transp. Manage. 14 (1), 20–26.

Liu, S., McDermid, J.A., 1996. A model-oriented approach to safety analysis using fault trees and a support system. J. Syst. Softw. 35 (2), 151.

Loader, R., Hobbs, J.E., 1999. Strategic responses to food safety legislation. Food Policy 24 (6), 685–706.

Loo, B.P.Y., Hung, W.T., et al., 2005. Road safety strategies: a comparative framework and case studies. Transp. Rev. 25 (5), 613–639.

Lund, J., Aarø, L.E., 2004. Accident prevention. Presentation of a model placing emphasis on human, structural and cultural factors. Saf. Sci. 42 (4), 271–324.

Lundberg, J., Rollenhagen, C., et al., 2009. What-you-look-for-is-what-you-find – the consequences of underlying accident models in eight accident investigation manuals. Saf. Sci. 47 (10), 1297–1311.

Makin, A.M., Winder, C., 2008. A new conceptual framework to improve the application of occupational health and safety management systems. Saf. Sci. 46 (6), 935–948.

May, M., Tranter, P.J., et al., 2010. Towards a Holistic Framework for Road Safety. The University of New South Wales at the Australian Defence Force Academy.

McGraw, C., Drennan, V., et al., 2008. Understanding risk and safety in home health care: the limits of generic frameworks. Qual. Primary Care 16 (4), 239–248.

McInerney, P.A., 2005. Final Report of the Special Commission of Inquiry into the Waterfall Rail Accident. Special Commission of Inquiry into the Waterfall Rail Accident. NSW Government, Sydney.

Miller, M.R., Takata, G., et al., 2011. Policy statement – principles of pediatric patient safety: reducing harm due to medical care. Pediatrics 127 (6), 1199–1210.

Mitropoulos, P., Abdelhamid, T.S., et al., 2005. Systems model of construction accident causation. J. Constr. Eng. Manage. 131 (7), 816–825.

Morley, F.J.J., Harris, D., 2006. Ripples in a pond: an open system model of the evolution of safety culture. Int. J. Occup. Safety Ergon. 12 (1), 3–15.

Mullai, A., Paulsson, U., 2011. A grounded theory model for analysis of marine accidents. Accid. Anal. Prev. 43 (4), 1590–1603.

Nader, R., 1965. Unsafe at Any Speed the Designed-In Dangers of the American Automobile. Grossman Publishers, New York.

Nadzam, D.M., Atkins, P.M., et al., 2005. Cleveland clinic health system: a comprehensive framework for a health system patient safety initiative. Qual. Manage. Health Care 14 (2), 80–90.

Newnam, S., Watson, B., 2011. Work-related driving safety in light vehicle fleets: a review of past research and the development of an intervention framework. Saf. Sci. 49 (3), 369–381.

Ng, C.M.Y., Chow, W.K., 2005. Proposed fire safety strategy on airport terminals. Int. J. Risk Assess. Manage. 5 (1), 95–110.

NHMRC, 2000. How to Review the Evidence: Systematic Identification and Review of the Scientific Literature. NHMRC, Canberra, Australia.

Nivolianitou, Z., Konstandinidou, M., et al., 2006. Statistical analysis of major accidents in petrochemical industry notified to the major accident reporting system (MARS). J. Hazard. Mater. 137 (1), 1–7.

NSTC, 2010. Draft Strategy for 2011 Environmental, Health and Safety (EHS) Research. NNI (National Nanotechnology Initiative) EHS Strategic Plan. National Science, Engineering and Technology Subcommittee, Committee on Technology, National Science and Technology Council (NSTC), USA.

O'Hare, D., 2000. The 'Wheel of Misfortune': a taxonomic approach to human factors in accident investigation and analysis in aviation and other complex systems. Ergonomics 43 (12), 2001–2019.

OECD, 2008. Towards Zero Ambitious Road Safety Targets and the Safe System Approach. Organisation for Economic Co-operation and Development, and International Transport Forum.

Perrow, C., 1984. Normal Accidents: Living With High-Risk Technologies. Princeton University Press, Princeton, NJ, USA.

Petticrew, M., 2001. Systematic reviews from astronomy to zoology: myths and misconceptions. BMJ 322 (7278), 98–101.

Poole, M., 1986. Industrial Relations: Origins and Patterns of National Diversity. Routledge & Kegan Paul, London.

Porter, S., Wettig, J., 1999. Policy issues on the control of major accident hazards and the new Seveso II directive. J. Hazard. Mater. 65 (1–2), 1–14.

Pun, K.-F., Hui, I.-K., 2002. Integrating the safety dimension into quality management systems: a process model. Total Qual. Manage. 13 (3), 373–391.

Rahimi, M., 1995. Merging strategic safety, health and environment into total quality management. Int. J. Ind. Ergon. 16 (2), 83–94.

Rasmussen, J., 1980. In: Smith, H.T., Green, T. (Eds.), The Human as a Systems Component. Human Interaction With Computers. Academic Press, London, pp. 67–76.

Rasmussen, J., 1982. Human errors – a taxonomy for describing human malfunction in industrial installations. J. Occup. Accid. 4 (2–4), 311–333.

Rasmussen, J., 1997. Risk management in a dynamic society: a modelling problem. Saf. Sci. 27 (2–3), 183–213.

Read, G.J.M., Salmon, P.M., Lenné, M.G., 2013. Sounding the warning bells: the need for a systems approach to understanding behaviour at rail level crossings. Appl. Ergon. 44 (5), 764–774.

Reason, J., 1990. Human Error. Cambridge University Press, Cambridge.

Redinger, C.F., Levine, S.P., 1998. Development and evaluation of the Michigan occupational health and safety management system assessment instrument: a universal OHSMS performance measurement tool. Am. Ind. Hyg. Assoc. J. 59 (8), 572–581.

Reniers, G.L.L., Ale, B.J.M., et al., 2006. Decision support systems for major accident prevention in the chemical process industry: a developers' survey. J. Loss Prev. Process Ind. 19 (6), 604–620.

Roelen, A.L.C., Lin, P.H., et al., 2011. Accident models and organisational factors in air transport: the need for multi-method models. Saf. Sci. 49 (1), 5–10.

Rothenberg, J., 1993. Social strategy and tactics in the search for safety. Crit. Rev. 7 (2–3), 159–180.

Runciman, W.B., Baker, G.R., et al., 2010. Tracing the foundations of a conceptual framework for a patient safety ontology. Qual. Saf. Health Care 19 (6), e56.

Runyan, C.W., Yonas, M., 2008. Conceptual frameworks for developing and comparing approaches to improve adolescent motor-vehicle safety. Am. J. Prev. Med. 35 (3 Suppl. 1), S336–S342.

Salmon, P.M., McClure, R., Stanton, N.A., 2012. Road transport in drift? Applying contemporary systems thinking to road safety. Saf. Sci. 50 (9), 1829–1838, http://dx.doi.org/10.1016/j.ssci.2012.04.011.

Sauter, S.L., Murphy, L.R., et al., 1990. Prevention of work-related psychological disorders. A national strategy proposed by the National Institute for Occupational Safety and Health (NIOSH). Am. Psychol. 45 (10), 1146–1158.

Sherman, H., Castro, G., et al., 2009. Towards an international classification for patient safety: the conceptual framework. Int. J. Qual. Health Care 21 (1), 2–8.

Standards Australia and Standards New Zealand, 2001a. AS/NZS 4801:2001 Occupational Health and Safety Management Systems – Specification With Guidance for Use. Standards Australia, Sydney.

Standards Australia and Standards New Zealand, 2001b. AS/NZS 4804:2001 Occupational Health and Safety Management Systems – General Guidelines on Principles, Systems and Supporting Techniques. Standards Australia, Sydney.

Standards Australia, 2006a. AS4292.1 Railway Safety Management: Part 1 General Requirements. Standards Australia, Sydney.

Standards Australia, 2006b. AS 4292.1-2006: Railway Safety Management – General Requirements. Standards Australia, Sydney.

Stang, E., 1996. Chernobyl – system accident or human error? Radiat. Prot. Dosim. 68 (3–4), 197–201.

Suraji, A., Duff, A.R., et al., 2001. Development of casual model of construction accident causation. J. Constr. Eng. Manage. 127 (4), 337.

Teo, E.A.L., Ling, F.Y.Y., et al., 2005. Framework for project managers to manage construction safety. Int. J. Project Manage. 23 (4), 329–341.

Van Urk, W., De Vries, W.A., 2000. POLSSS: policy making for sea shipping safety. Saf. Sci. 35 (1–3), 139–150.

Underwood, P., Waterson, P., 2013a. Systems thinking, the Swiss Cheese Model and accident analysis: a comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models. Accid. Anal. Prev., http://dx.doi.org/10.1016/j.aap.2013.07.027.

Underwood, P., Waterson, P., 2013b. Systemic accident analysis: examining the gap between research and practice. Accid. Anal. Prev. 55, 154–164.

Von Bertalanffy, L., 1968. General System Theory: Foundations, Development, Applications. Penguin, Braziller, Harmondsworth, Middlesex.

Vernez, D., Buchs, D., et al., 2003. Perspectives in the use of coloured Petri nets for risk analysis and accident modelling. Saf. Sci. 41 (5), 445–463.

Vincent, C., Taylor-Adams, S., et al., 1998. Framework for analysing risk and safety in clinical medicine. BMJ 316 (7138), 1154–1157.

Wallis, K., Dovey, S., 2011. Assessing patient safety culture in New Zealand primary care: a pilot study using a modified Manchester patient safety framework in Dunedin general practices. J. Primary Health Care 3 (1), 35–40.

Wang, W., Jiang, X., et al., 2010. Incident tree model and incident tree analysis method for quantified risk assessment: an in-depth accident study in traffic operation. Saf. Sci. 48 (10), 1248–1262.

Waterson, P., 2009. A critical review of the systems approach within patient safety research. Ergonomics 52 (10), 1185–1195.

Wegman, F., Holló, P., et al., 1995. Road Accidents: Worldwide a Problem that can be Tackled Successfully!. Leidschendam, SWOV.

Weinstein, M.B., 1996. Total quality approach to safety management. Prof. Saf. 41 (7), 18–22.

Whitefield, D., 2009. Is that a gap in your safety culture – a discussion paper on leading safety excellence. In: Society of Petroleum Engineers – SPE/IATMI Asia Pacific Health Safety, Security and Environment Conference and Exhibition 2009, APHSSEC 09, Jakarta.

WHO, 2009. Global status report on road safety. World Health Organisation, Geneva.

WHO, 2010. Equity, Social Determinants and Public Health Programs. World Health Organisation, Geneva.

Wiegmann, D.A., Shappell, S.A., 2003. A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System. Ashgate, Aldershot, UK.

Wildavsky, A., 1989. The secret of safety lies in danger. Society 27 (1), 4–5.

Wilson, J.R., 2014a. Fundamentals of systems ergonomics/human factors. Appl. Ergon. 45 (1), 5–13.

Wilson, J.R., 2014b. Systems ergonomics: looking into the future. Appl. Ergon. 45 (1), 3–4.

Zhou, Q., Fang, D., et al., 2008. A method to identify strategies for the improvement of human safety behavior by considering safety climate and personal experience. Saf. Sci. 46 (10), 1406–1419.