

Article

Methods and Models for Disaster Risk Reduction in Urban Areas Through Transport Systems: Research Directions from Planning, Training, TSM, e-ICT

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Abstract

Disaster risk reduction, both natural and man-made, is a global priority and is in line with the goals of the 2030 Agenda, defined on the basis of what happened at the beginning of the millennium, starting with the disaster in human lives caused by Katrina in New Orleans. However, there is a scientific gap between the level of risk and the planned risk mitigation measures, with the related training and exercise actions implemented before real-life emergencies happen. In the context of Transport Risk Analysis (TRA), the size of exposure (E), in particular its reduction through evacuation, has been little studied, unlike the dimensions of occurrence (O) and vulnerability (V). This study aims to provide a framework of the scientific literature on the risk exposure component (graphical abstract) in urban transport systems, focusing on four macro areas: planning process; training and exercises; advanced Transport System Models (TSM); and use of emerging ICT (e-ICT). The study has been carried out using forward snowball techniques on a selected sample of the literature. The final set of references comprises 165 publications: 149 retrieved from Scopus (including records assessed at abstract level) and 16 retrieved via Google Scholar and forward-citation snowballing. The publications are distributed across the four macro-areas as follows: 68 concern the planning process, 24 training and exercises, 61 advanced Transport System Models, and 12 the use of e-ICT. The four macro-areas were examined both individually and in their mutual intersections, since several publications address more than one area simultaneously. Each work was classified under its predominant area for tabulation purposes. The analysis shows that the literature examined provides unequal coverage of the four broad areas. Whilst contributions relating to the planning process and modeling are relatively well-established, the integration of ICT with advanced transport system models in the context of transport risk analysis remains extremely limited. Approaches based on forecasts for outdoor evacuation are largely absent, and research into training and drill activities lags behind that on planning models. The framework developed in this work is useful to researchers, policy makers and public sector technicians involved in emergency management, as it offers a clear framework to guide future work in both research and operational action.



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Keywords: disaster risk reduction; exposure; evacuation; transport system models; transport risk analysis; emerging ICT

1. Introduction

Sustainable development has disaster risk reduction among its objectives. Formulated in 2015, the Agenda 2030 for Sustainable Development (Goals 1, 11 and 13) [1–3] and the Sendai Framework for Disaster Risk Reduction represent the key policy frameworks for risk governance at the global level [4]. These frameworks suggest planning universally applicable evacuation procedures to improve the community's resilience and set measurable targets for disaster risk reduction by 2030.

The goals of the 2030 Agenda derive from the observation of what has happened. Just remember the aggregate quantity of disasters in the last 10 years that have led to more than 250 million displaced people [5] or recall the disaggregated data relating to the victims of Hurricane Katrina or the Fukushima tsunami at the start of the millennium.

The planning of evacuation procedures on an urban scale is currently done with prescriptive measures. A new approach has been provided in the field of fire safety and building evacuation planning [6], so that two methodological approaches are now available: the traditional prescriptive and the innovative performance-based. The first is defined by fixed and conservative standards, which guarantee a universally applicable minimum level of safety. The second is based on fire safety engineering [7] and evaluates the safety performance on a case-by-case basis, allowing for specific and cost-effective design solutions. The ISO/TR 13387-1:1999 reported [7] define:

Prescriptive regulations: Regulations that achieve their fire safety objectives, and/or components of those objectives, by specifying what has to be provided.

Performance-based regulations: Regulations that specify explicitly their objectives and/or components of these objectives, in terms of quantifiable criteria that shall be satisfied.

Performance planning, in an extremely schematic way, involves the quantitative analysis of two parameters:

- the time available for evacuation (ASET), i.e., the time between event and effect;
- the time required for evacuation (RSET), i.e., the time to evacuate the population.

The necessary condition to ensure safety is that:

$$RSET < ASET \quad (1)$$

The purpose of this article is to extend this performance-based approach to evacuation on an urban scale through different components: planning process (planning); training and exercises (t & e); advanced Transport System Models (TSM); and use of emerging ICT (e-ICT). In this way, it is possible to evolve the terms of Equation (1), considering that ASET is defined in the Occurrence and RSET in the Exposure:

$$\begin{aligned} ASET &= f(\text{occurrence}) \\ RSET &= g(\text{exposure}) = g'(\text{planning}; t \& e; \text{TSM}; e\text{-ICT}) \end{aligned}$$

The gap between, on the one hand, the actual effective risk level and, on the other hand, the planned risk mitigation with the concrete measures to be taken during a disaster can be bridged by investing in training activities and exercises during the preparedness phase, as well as by implementing advanced transport models that allow for realistic situations to be reproduced during the mitigation phase. The effectiveness of an emergency plan depends on the transport system, which allows the evacuation of the population from dangerous areas to safe places.

The general objective is, therefore, to deepen the increase in resilience thanks to social knowledge or, in a synthetic way, "Recovering Increasing by Social Knowledge". These capabilities must be developed in all phases of the Risk Management Cycle (mitigation,

preparedness, response, and recovery) (Figure 1) defined by the United Nations [4]. However, the greatest attention must be paid to the first two phases in which the systems can be organized to be reactive by intervening at the right time.

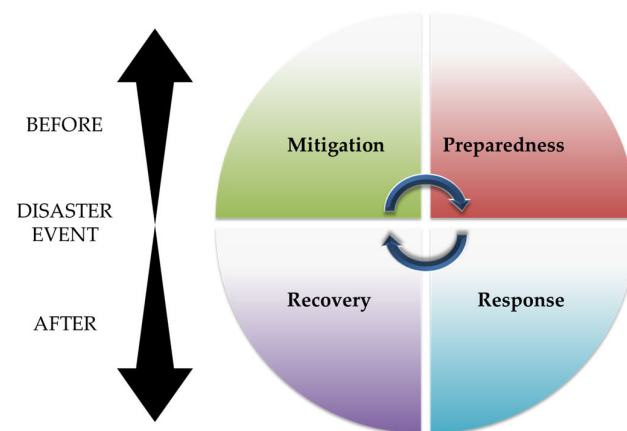


Figure 1. Disaster cycle management.

The aim of this study is to offer a review of the relevant literature for the analysis of risk exposure in the transport sector, summarizing the reference framework in some main areas (Figure 2) closely related to each other:

- Planning process, to be developed during the mitigation phase;
- Training and exercise activities, to be developed during the preparedness phase;
- Advanced transport systems models (Advanced TSMs), to be developed in both phases;
- Dynamic assignment models (DTAs), to be developed in both phases.

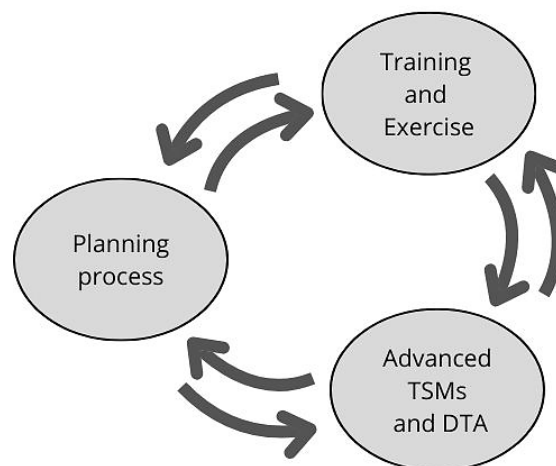


Figure 2. Main areas of research.

The hypothesis underlying this bibliographic analysis is that the plan and training actions are developed within a definable performance approach, in line with the definition used for building evacuations. To be valid, the actions must allow exposure to be reduced by verifying equations of type 1. Transport System Models (TSMs) allow you to estimate RSET-type indicators.

Training and exercises perform a dual function, being the operational tool that connects theoretical planning to reality:

- Increase readiness, capability and awareness on the part of users. Both discussion-based and operation-based exercises increase capability and awareness and improve

the readiness of all parties involved, ensuring that, in the event of an emergency, procedures are implemented correctly;

- Acquire data to calibrate and validate performance models. The empirical results obtained from the exercises can represent the parameters to be included in the TSMs.

After the introductory section, the second chapter recalls and summarizes the main literature on risk exposure. The main references to transport system models, transport risk analysis and exercise and training actions aimed at increasing emergency preparedness are recalled. The third chapter presents the literature review, selecting the main contributions for each of the dominant areas. The fourth chapter is reserved for some general conclusions; it identifies the directions of greatest potential research development, starting with the use of emerging Information and Communication Technology (e-ICT). It should be noted that various technologies are here defined as emerging ICTs that are already mature in their respective original fields of development, while applications in transport systems are currently experimental, prototype or otherwise unconsolidated.

This work is mainly aimed at civil protection and transport planners, emergency managers, researchers and local and national policy makers with the aim of offering a scientific framework to reduce the risk of exposure of communities in the event of an emergency.

2. Exposure Reduction: General Literature for the Four Main Areas

2.1. Planning Processes

The methodology adopted for risk assessment in transport is the Transport Risk Analysis (TRA) [8–10], in which risk is formalized with a model consisting of three elements: the probability of occurrence of an event, the probability of potential damage to infrastructure (vulnerability) and the probability relative to the amount of people and assets involved (exposure). In emergency management, reducing the last factor is the primary goal of evacuation plans.

The effectiveness of plans can be assessed through Decision Support Systems (DSS) [11,12], tools that integrate technologies such as GIS (geographic information systems), ITS (intelligent transport systems) and VGI (voluntary geographic information) to analyze and optimize strategies in complex scenarios. Their operation follows the logical framework approach (LFA), which defines a hierarchy of cause and effect. Each element of the process is quantified through SMART (Specific, Measurable, Attainable, Realistic, Timed) indicators. The values of the indicators are calculated and validated by combining the TRA models with the Evaluation methods (Figure 3). The entire cycle of an evacuation plan, which includes design, implementation and monitoring, is followed by Project Cycle Management (PCM), which is responsible for aligning the plan with the standards and processes required by funding bodies.

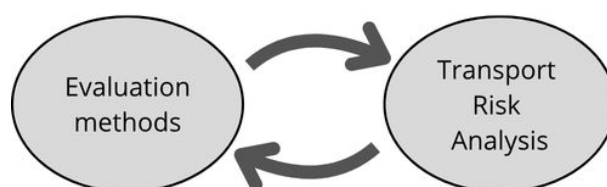


Figure 3. Planning process.

2.2. Training and Exercises

Theoretical planning alone does not guarantee effective execution of planned actions. To implement the information contained in the plan, training and practical training activities must be implemented. These exercises have direct consequences on the preparedness of

operators and the population, contributing in a quantifiable way to the reduction of risk exposure [13]. The types of exercises are mainly divided into two categories [14]:

- Exercises based on discussion conducted in a controlled environment with low stress; seminars, workshops, table-top and games belong to this category;
- Exercises based on operations that simulate the conditions of a real emergency; drills, functional exercises and large-scale exercises belong to this category.

The complexity of the exercise activities is measured on the basis of the number of subjects involved, the resources used, and the ability to achieve defined objectives, such as the reduction of evacuation times.

The preventive impact of each exercise on reducing exposure is estimated with simulation behavioral models (Figure 4).

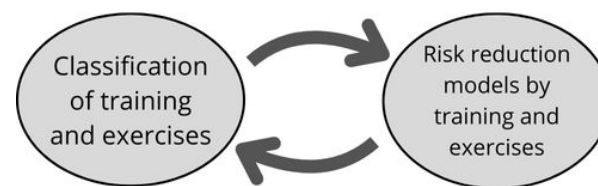


Figure 4. Training and exercises.

2.3. Advanced Models of Transport Systems

The simulation of evacuation procedures is carried out by applying Transport Systems Models (TSM), whose components are:

- Mobility demand, which represents users' choices regarding available network and service options;
- Transportation supply, which analyzes the costs associated with the use of infrastructure;
- Assignment, which is the process of interaction between supply and demand that determines the actual traffic flows on the network.

Demand modeling can follow a stochastic approach with behavioral models, which reconstruct the decision-making process of the individual user based on utility criteria, e.g., Random Utility Models, Quantum Utility Models, or Fuzzy Utility Models [15–23], or a descriptive approach, which uses aggregate relationships between demand and network characteristics.

Supply is typically represented with established topological models, where the network is described by nodes and links, each of which is associated with a cost function. Models that allow us to study the levels of centrality of the nodes of a network are those based on network analysis [24–26].

The interaction between these two components is simulated through traffic assignment models. In an ordinary scenario, static assignment models (STAs) are generally used. In an extraordinary scenario such as an emergency scenario that is rapidly evolving, dynamic assignment models (DTAs) are suitable. DTA models allow network changes to be represented by simulating the upgrade of the utilities of alternatives and user choices [27–30]. For the analysis of risk propagation mechanisms in transport networks, the work by Su et al. (2026) [31] provides important theoretical support for understanding the dynamics of cascading failures in interconnected systems.

The temporal variation of flows is modeled with within-day models (which analyze the evolution of traffic over the course of a day) and day-to-day models (which consider variations over several days) [32,33].

2.4. e-ICT DTA

In the risk scenario, the evolution of events causes a variation in periodic traffic that can be modeled with period-to-period models. An advanced dynamic approach (Dynamic Traffic Assignment, DTA) considers the learning process of users, who can modify their choices based on previous experiences or information received in real time (through e-ICT technologies). This new possibility provided by e-ICT increases the response capacity of users subject to risk because it increases their knowledge. Traditional learning processes are profoundly modified by e-ICTs, as can be easily verified in the literature. To capture this dynamic, it is necessary to implement period-to-period models that are capable of accurately estimating the continuous updating of the utilities of the alternatives available to the user with travel choices in the context of an evacuation [34] (Figure 5). The new DTA model using e-ICT can be indicated as e-DTA. e-DTA represents the qualitative leap, which translates into something quantitative that produces social knowledge and allows you to reduce risk.

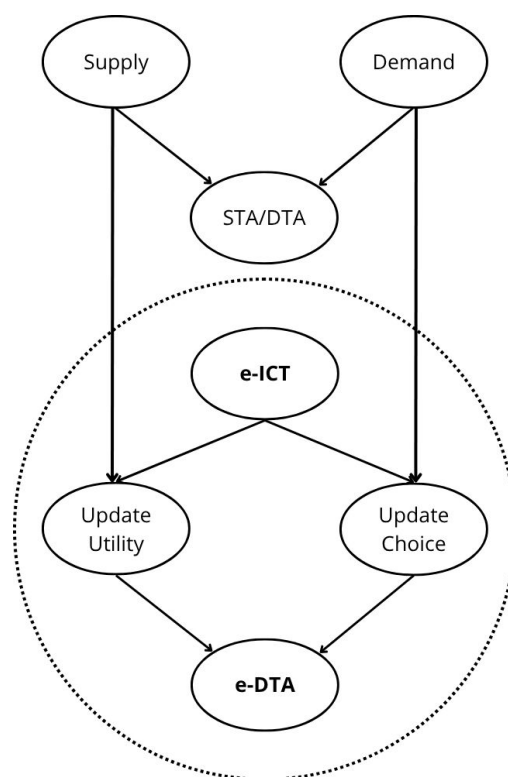


Figure 5. Advanced TSMs with e-DTA.

e-ICT technologies are mature in other civil and/or industrial sectors but are still little used and developed in the transport sector. They can be classified in relation to their functional use and not with respect to their intrinsic technology, so tools with profoundly different technologies can belong to the same e-ICT class. The main classes of e-ICT that must be recalled are:

- IoT, Internet of Things, technologies that allow data to be collected, transmitted, elaborated and shared in real time;
- BD, Big Data, technologies that allow data to be quickly extracted from large databases;
- BC, Blockchain, or Internet of Value (IoV), are technologies that allow economic transactions to be tracked in complete security;
- AI, Artificial Intelligence, technologies that allow for confronting and ordering solutions in different fields;

- DT, Digital Twin, technologies that allow for creating a virtual version of reality where the impacts of technical choices can be simulated.

The focus here is on the potential for integrating the technologies described above with the DTA, as the main direction of the research is the development of e-DTA models capable of utilizing these technologies for real-time evacuation management and the reduction of exposure.

3. Exposure Reduction: Specific Literature on Evacuation for the Four Main Areas

3.1. The Method and the Overall Framework

In this section, the four macro areas presented in the previous section are examined in depth, where the general literature for each area has been reported. The specific literature for each of them is analyzed, looking for which ones are the works that, for each area, deepen the theme of evacuation in a risk context. The literature search was conducted using two databases, Scopus and Google Scholar, and covers publications from 2000 to 2026, with the search itself carried out up to January 2026. The final corpus comprises 165 publications: 149 retrieved via Scopus and assessed at a full-text level (where the full text was not accessible, they were assessed on the basis of title, keywords and abstract); and 16 retrieved via Google Scholar and forward-citation snowballing. The resulting corpus is distributed across the four broad areas, as follows: 68 publications on the planning process, 24 on training and exercises, 61 on advanced transport system models and 12 on the use of emerging ICTs.

The theoretical structure is configured as a matrix in which the scientific contributions of reference are identified by the cells obtained from the intersection of a methodological dimension with a specific literary area. In turn, due to its schematic nature, the structure of the literature can be represented with a tree, as in Figure 6.

It should be noted that many articles may relate to more than one specific area. For the purposes of tabulation, several articles have been classified according to their predominant area, whilst the matrix structure adopted (Figure 6) also takes account of the overlaps between them. Each paper is included in the specific areas most extensively covered. The tables presented in the following paragraphs list the keywords provided by the authors of the various papers cited.

The bibliographic research has been developed with the technique called ‘snowball forward’ which consists of progressively expanding the collection of sources starting from an initial nucleus of documents. The forward technique considered identifies the basic works (seed papers) and then the subsequent works that refer to the basic works. The forward technique differs from the backward technique because the latter follows the citation contained in the basic works.

The snowball technique was preferred to a search based solely on keywords, as the four broad areas under study are niche topics for which no standardized terminology has yet been established. A purely lexical search would risk excluding relevant contributions. By starting with highly cited reference articles and tracing their citations forward, it is possible to identify even the most recent works that build on these seminal contributions.

The search algorithm is simple and is divided into the following steps:

- Initial document (seed paper);
- Search for citations received;
- Selection of relevant works;
- Iteration where significant works can become seed papers.

Seed papers have been identified as the most cited works for the specific thematic area considered. The technique used is very useful because it allows for identifying the most recent works. In particular, SICURO and RISK were chosen as the main reference sources because, from the reconnaissance and reconstruction carried out, they are the only two large-scale Italian research programs entirely dedicated to reducing risk exposure through evacuation using transport systems. Although this choice is somewhat innovative for a review article, it carries a potential risk of selection bias: over-reliance on the results of two projects could lead to insufficient coverage of the international literature. However, as demonstrated by the results, the inclusion of individual international articles ensures broader geographical and thematic coverage.

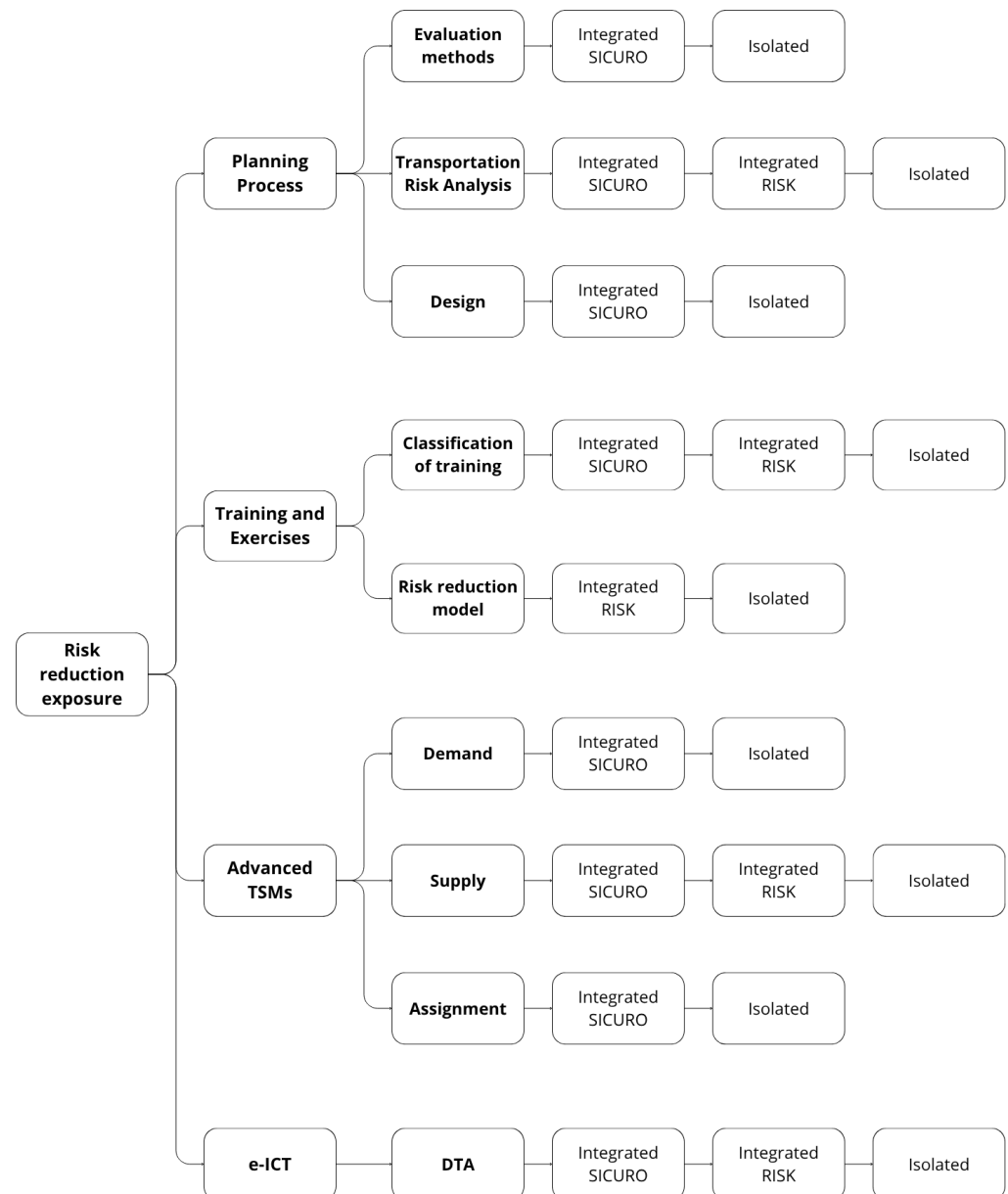


Figure 6. Analysis of the literature.

In the following, “integrated papers” are indicated as scientific papers conceived and developed within a structured research project, characterized by thematic, methodological and/or theoretical value, and aimed at building a unitary and synergistic corpus. “Isolated papers” are defined as those works produced outside of an overall research design, born

from individual research or specific scientific interests and without systematic integration with other scientific outputs. The term “isolated” is not intended to denote a lack of scientific influence but rather the absence of a shared, coordinated research–program structure.

The development of the literature study allows us to identify distinct groups of publications: The first and second groups collect, respectively, the contributions of two important Italian national research projects, SICURO and RISK, specifically dedicated to the study of risk exposure reduction through evacuation plans and adequate training/exercise facilities and are, therefore, integrated. The third group includes the isolated international literature. It should be noted that the first two groups differ from the third because they have a remarkable coherence and integration, with identical definitions and bases of reference, thus constituting a homogeneous whole.

3.2. Planning Process

The papers that deal with the different aspects of the planning process for the reduction of exposure are developed in the “mitigation” phase. Several articles focus on the quantitative estimation of risk exposure [10,35–72] and the importance of DSSs for real-time data collection and support for evacuation planning [54,73–79]. In particular, some papers focus on the integration of discrete-choice simulation models and dynamic transport assignment (DTA) into DSSs to support real-time evacuation management [30,49,52,80–100]. It is important to note that, in general, the methods for evaluating scenarios and ordering them can be divided into two classes: “what if” and “what to”. In the bibliographic reconstruction presented below, the definition “evaluation methods” is used for what if methods, as commonly done in the literature. The term “design” is used in the scientific literature that refers to what to methods. On this basis, the works obtained from the bibliographic analysis can be divided into three specific areas (Figure 6):

- Evaluation methods;
- Transportation risk analysis;
- Design.

The reviewed literature on the planning process reveals a strong emphasis on quantitative risk assessment and DSS development, with a clear predominance of works from the SICURO project in the areas of evaluation methods and TRA. The international literature is more fragmented, with contributions spanning various aspects of evacuation planning, vulnerability analysis, and optimization. Notably, the RISK project has recently contributed to the integration of emerging technologies into risk analysis frameworks. However, the overall planning literature remains largely focused on prescriptive approaches, with limited integration of dynamic, performance-based methodologies for urban-scale evacuation.

3.2.1. Evaluation Methods

In this paragraph, the reference works in the context of evaluation methods are reported. In particular, in Table 1 are the works developed in the SICURO project and, in Table 2, the individual works on an international scale. There is no work on the evaluation methods developed in the RISK project.

Table 1. SICURO papers.

Authors	Year	Keywords
Russo & Rindone [74]	2010 (a)	Evacuation planning, evaluation methods, efficiency, Data Envelopment Analysis
Russo & Rindone [75]	2010 (b)	Evacuation plan, evaluation methods, efficiency, parametric and non-parametric methods
Russo & Rindone [76]	2012	Evacuation planning, evaluation methods, DEA

Table 2. International papers.

Authors	Year	Keywords
Uno & Kashiya [73]	2008	Multi-agent model; GIS; virtual reality; evacuation analysis; flood flow
Herrera-Restrepo et al. [77]	2016	Evacuation planning performance; dynamic network DEA; evacuation traffic management strategies; infrastructure systems as processes
Budzynski et al. [54]	2021	Epidemic; COVID-19; risk in transport
Ghorbanzadeh et al. [78]	2021	Hurricane evacuations; evacuation modeling; storm surge modeling; ADCIRC + SWAN; Hurricane Irma
Nurwatik et al. [79]	2022	Healthcare; accessibility; network analysis; vulnerability; open source

3.2.2. Transportation Risk Analysis

This paragraph shows the reference works in the field of transportation risk analysis. In particular, Table 3 shows the works developed in the SICURO project, in Table 4 the works developed in the RISK project. In Table 5, the individual works on an international scale.

Table 3. SICURO papers.

Authors	Year	Keywords
Russo & Vitetta [35]	2005	Risk analysis, evacuation, simulation, network design
Russo & Vitetta [10]	2006	Evacuation, network design, risk analysis, simulation
Russo & Vitetta [36]	2007	Risk analysis, transportation models
Russo & Rindone [37]	2007	Planning process, evacuation, guidelines, system of models
Vitetta et al. [38]	2007	Evacuation, path design, emergency vehicle.
Russo & Rindone [40]	2008	Planning process, LFA, evacuation, system of models
Russo & Rindone [42]	2009	Planning process, evacuation plan, logical framework approach, software
Russo & Rindone [43]	2011 (a)	Transportation planning, evacuation planning, classification of interventions
Russo & Rindone [44]	2011 (b)	Planning process, evacuation plan, logical framework approach
Russo & Rindone [45]	2013 (b)	Dangerous goods, road accident, risk analysis, occurrence, performance
Rindone & Panuccio [55]	2021	Emergency, risk, exposure, evacuation, urban planning
Di Gangi & Belcore [53]	2021	Decision support system, evacuation modelling, emergency management, GIS
Rindone & Panuccio [60]	2023	Emergency, evacuation, exposure, risk, urban planning

Table 4. RISK papers.

Authors	Year	Keywords
Astarita et al. [61]	2024	Digital twins; urban risk management; predictive analysis in urban planning; disaster response and mitigation; urban resilience and sustainability

Table 4. *Cont.*

Authors	Year	Keywords
Russo & Rindone [62]	2024 (c)	Environmental risk assessment; Risk formulation; Risk map
Russo & Rindone [67]	2025	Transport of dangerous goods; Sustainable development; WebGIS; Transport risk analysis; Transport system models; Sustainable planning; Occurrence; Vulnerability; Exposure
Astarita et al. [69]	2025 (a)	Urban risk management; Predictive analysis in urban planning; Disaster response; mitigation; Urban resilience; sustainability; Artificial Intelligence
Jafarzadeh et al. [68]	2025	Behavior of drivers; road transportation; young drivers; MARCOS; intuitionistic fuzzy environment
Astarita et al. [70]	2025 (b)	Blockchain; Disaster occurrence; Risk reduction; Trust; Data privacy; Recovery Database
Martino et al. [71]	2025 (b)	Big Data; Human Behaviors; Congested Traffic; Environmental Disaster; Event Forecasting; Climate Change

Table 5. International papers.

Authors	Year	Keywords
Anastassiadis & Argyroudis [39]	2007	Earthquake; risk management; road network; seismic risk; urban system; vulnerability
Cirianni et al. [41]	2008	Lifelines; Highway; Seismic risk assessment; Vulnerability; AHP
Cirianni et al. [46]	2013	Spatial planning, processes, commercial functions, city logistics
Tai et al. [47]	2014	Evacuation behavior, logistic regression model, shelter
Rupi et al. [48]	2015	Link importance; link disruption; generalized trip cost; Spearman correlation coefficient
Kim et al. [51]	2018 (a)	Flight Management System; Numerical Simulation; Heading Angle; Small Unmanned Aircraft System; Airspace; Air Traffic Controller; Monte Carlo Simulation; Level Flight; Probability Distribution Functions; Air Traffic Management
Kim et al. [50]	2018 (b)	Small Unmanned; Conflict Risk; Unmanned Aircraft; Aircraft Systems; Risk Analysis; Risk; sUAS; Conflict; Unmanned; Small
Liu et al. [56]	2021	Route planning; cruise ship; IACS; emergency evacuation
Deng et al. [57]	2022	Public safety; fire evacuation; panic; eye movement; haemodynamics; statistical analysis
Iiritano et al. [58]	2022	Limited Traffic Zone; Urban planning; Sustainability; Schools; Safety; COVID-19
Wang & Ozbay [59]	2023	Public transportation; buses; sustainability and resilience; disaster response; recovery; and business continuity; emergency evacuation
Henke et al. [63]	2024	Vulnerability analysis; accessibility indicator; link importance indicator; human urban mobility; traffic disruptions

Table 5. *Cont.*

Authors	Year	Keywords
Lyashuk et al. [64]	2024	Road transport accidents, risk analysis, traffic safety, risk management, statistical analysis, safety interventions
Zou & Kang [65]	2024	Time-varying conditions; hazardous chemicals transportation; vehicle routing problem; multiobjective optimization
Salvatore et al. [66]	2024	Existing tunnels; geotechnical; structural risk; road accident; traffic risk; interventions optimization
Kovalenko et al. [72]	2025	Transportation; transport risk; intelligent transport system; integrated transport system; risky situation; emergency situation during route transport; transport companies

3.2.3. Design

In this section are reported reference works in the field of design. In particular, Table 6 shows the works developed in the SICURO project, and Table 7 shows the international isolated works. There is no work on the design developed in the RISK project.

Table 6. SICURO papers.

Authors	Year	Keywords
Vitetta et al. [80]	2008	Evacuation; cost functions; microscopic models
Vitetta et al. [81]	2009 (a)	-
Vitetta et al. [82]	2009 (b)	DSS for evacuation planning; supply; demand-supply interaction
Polimeni et al. [84]	2010 (b)	Evacuation; emergency conditions; what to models
Polimeni et al. [85]	2010 (c)	Signal setting; paths design; road supply; evacuation conditions
Polimeni et al. [83]	2010 (a)	Evacuation; path design; vehicle routing problem; emergency conditions
Polimeni & Vitetta [86]	2011 (a)	Time-dependent networks; path design; emergency conditions
Polimeni & Vitetta [87]	2011 (b)	Time-dependent network; dynamic shortest path algorithm; route design; emergency conditions
Polimeni & Vitetta [89]	2012 (b)	Vehicle routing; link cost functions; network monitoring
De Maio et al. [90]	2012	Intelligent Transport System (ITS); route choice; dynamic traffic assignment; emergency conditions
Vitetta [95]	2021	Emergency condition; network design problem; vehicle routing problem; risk reduction
Vitetta [30]	2022 (b)	Evacuation; risk reduction transport; network design problem

Table 7. International papers.

Authors	Year	Keywords
Lim et al. [88]	2012	Capacitated network flow problem; Evacuation planning; Time-expanded network; Shortest path
Goerigk et al. [91]	2014	Disaster management; Evacuation planning; Location-routing; Multi-criteria genetic algorithms; Data aggregation

Table 7. *Cont.*

Authors	Year	Keywords
Paul [49]	2015	Unit-segment analysis; Space syntax; City configuration; Urbanization; Urban variables; Space–people relationship; Human city
Wu et al. [92]	2018	Contraflow; lane reconfiguration; evacuation planning; capacity constraints
Dulebenets et al. [93]	2019	Natural hazards; Emergency evacuation; Vulnerable populations; Optimization; Heuristics; Travel time
Liu et al. [94]	2019	Assignment, supply network
Kamishetty & Paruchuri [52]	2020	Emergency Evacuation; Intelligent Transportation; Pareto Solutions; Min-Cost Max Flow Algorithm; Traffic Theory; Modeling and Simulation; Cooperative Driving; Traffic Management
Diallo et al. [96]	2023	H3 indexing; emergency vehicles; vehicle route optimization; response time
Li et al. [97]	2023	The elderly; Perceptions of the living environment; Earthquake; Residential area Neighborhood
Wang et al. [98]	2023	Climate change; urban rail transit; optimal renovation sequence; optimal investment timing
Yang Liu et al. [99]	2023	Multimodal Transport; Network Planning and Design; Ideal Point Method
Lotero et al. [100]	2024	Ford-Fulkerson algorithm; Mine fire emergency; Mine ventilation simulation; Self-evacuation

3.3. Training and Exercises

The works that deal with the different aspects of the main area of training and exercises are developed in relation to the phase called “preparedness”. These studies provide accurate classifications of training activities based on the type of exercise and highlight the need for standardization at the European level to improve emergency preparedness and response [101–117]. Furthermore, they provide operational tests [57,118–123]. These works can be divided into two homogeneous areas:

- Classification of training and exercise actions;
- Risk reduction model by means of training and exercises.

The literature on training and exercises is significantly less developed than that on planning, with a clear gap between the US approach (which offers a structured framework through FEMA’s HSEEP) and the more fragmented European and Asian contributions. The RISK project has made important contributions to the classification of exercises and the development of evaluation models, but the international literature remains sparse. Emerging research directions include the use of serious games and ICT-based training tools, which represent promising but still prototype-level developments. The overall lack of standardized evaluation models for training effectiveness is a notable gap across all research groups.

3.3.1. Classification of Training and Exercises

In this paragraph, the reference works in the context of the classification of training and exercises are reported. In particular, in Table 8, the works developed in the SICURO project, in Table 9, the works developed in the RISK project, and in Table 10, the individual works on an international scale.

Table 8. SICURO papers.

Authors	Year	Keywords
Russo et al. [101]	2012	Evacuation planning; training; discussion-based
Russo & Rindone [102]	2013 (a)	Civil risk; planning; training; certification; standard
Russo & Rindone [103]	2014	Disaster risk reduction; exposure; evacuation; risk analysis; training; performance

Table 9. RISK papers.

Authors	Year	Keywords
Russo & Rindone [106]	2024 (a)	Disasters; emergency planning; risk analysis; transport planning; evacuation planning; exercises; transport system models
Russo & Rindone [107]	2024 (b)	Disaster risk; risk reduction; evacuation planning; exercises

Table 10. International papers.

Authors	Year	Keywords
Wang et al. [104]	2021	Hurricane; evacuation; ride-sourcing; shared mobility; pricing strategy; subsidy; demand and supply; social equity
Appleby-Arnold et al. [105]	2021	Citizen summit; Disaster preparedness; Culture; Community cohesion; Self-efficacy
Sobczuk & Borucka [108]	2024	Sustainable transport; transport development; modern solutions; global crises; military conflicts; COVID-19 pandemic; climate crisis; migration; literature review
Polydoropoulou et al. [109]	2024	Resilience; maritime ports; Decision Support System; Climate change
Wang et al. [110]	2024	Cruise ship; evacuation simulation; ship motion; ship inclination
Saha et al. [111]	2024	Travel behaviors; trips; accessibility; driving; ride hailing
Alakrawi et al. [112]	2024	Disaster planning; educational measurement; emergency responders; paramedics; program evaluation; simulation training
Zhang et al. [113]	2024	Feature extraction; driving style; principal component analysis; K-means clustering; support vector machine
Xie et al. [114]	2025	Evacuation simulation; pedestrian movement; decision adaptation; 3D indoor environment; emergency management
Becerra Saguma et al. [115]	2026	Gestión; prevención; políticas
Ruoslahti & Lonka [116]	2025	System, Structures, Processes, Civil Protection Exercises, Exercise Evaluation
Sandoval-Díaz et al. [117]	2025	Community resilience; Wildfire risk; Disaster risk governance; Urban-rural interface; Adaptation strategies; Disaster risk reduction

3.3.2. Risk Reduction Model by Means of Training and Exercises

In this paragraph, the reference works in the field of risk reduction models are reported. In particular, in Table 11, the works developed in the RISK project, and in Table 12, the individual works on an international scale. There is no work on the risk reduction model by means of training and exercises developed in the SICURO project.

Table 11. RISK papers.

Authors	Year	Keywords
Rindone & Moschella [119]	2024	Disaster risk; Exposure; evacuation planning; training and exercises; seminars
Rindone & Russo [120]	2025 (a)	Sustainability; disaster risk reduction; serious game; transport system models; ICT
Russo et al. [122]	2025 (c)	Risk analysis; Exposure; Evacuation; Stated Preference (SP); Survey; Demand analysis; Updated choice; Information and Communication Technologies (ICTs)
Martino et al. [121]	2025 (a)	Emergency Management; Warning Systems; Risk Reduction
Rindone et al. [123]	2025	Risk; urban evacuation; Technology Acceptance Model (TAM); pilot survey

Table 12. International papers.

Authors	Year	Keywords
Tang & Feng [118]	2018	Disaster preparedness; protection motivation theory; earthquake; Taiwan
Deng et al. [57]	2022	Public safety; fire evacuation; panic; eye movement; statistical analysis

3.4. Advanced TSMs

Studies that deal with the use of TSMs, with the necessary progress towards their deployment in extraordinary conditions arising from disaster risk reduction, relate both to the ‘mitigation’ phase, as they must be taken into account when reporting on plans, and to the ‘preparedness’ phase, as they enable the impact of capabilities to be simulated and thus the pursuit of the SDGs of the 2030 Agenda. These articles can be categorized into homogeneous areas:

- Demand [29,124–144];
- Supply [89,145–157];
- Assignment [158–182].

The literature on advanced TSM models is the most developed and mature of the four macro-areas, with a well-established corpus of work covering demand, supply and allocation modeling. The SICURO project has produced a particularly rich body of work in all three sub-areas, whilst the international literature offers studies on evacuation behaviour, network vulnerability and dynamic allocation. However, a significant gap remains in the integration of these models with real-time data from emerging technologies. Recent contributions from RISK represent important steps towards bridging this gap, but the sector as a whole still lacks a unified framework for modeling evacuation dynamics.

3.4.1. Demand

This section lists the relevant studies relating to ‘demand’ in the context of evacuation. Specifically, Table 13 presents the work carried out as part of the SICURO project, whilst Table 14 shows individual studies conducted at an international level.

Table 13. SICURO papers.

Authors	Year	Keywords
Russo & Chilà [124]	2007	Emergency conditions; simulation; demand model
Russo & Chilà [125]	2008	Emergency conditions; simulation; demand model

Table 13. *Cont.*

Authors	Year	Keywords
Russo & Chilà [126]	2009	Evacuation conditions; calibration; estimation; demand models
Russo & Chilà [128]	2010 (a)	Evacuation conditions; sequential dynamic demand model; sequential test
Russo & Chilà [129]	2010 (b)	Evacuation conditions; sequential dynamic demand model
Russo & Chilà [131]	2011 (a)	Evacuation conditions; hypothetical scenarios
Russo & Chilà [132]	2011 (b)	Evacuation conditions; demand model
Musolino & Vitetta [133]	2011	Within-day traffic assignment; dynamic vehicle routing; short-term forecasting
Russo & Chilà [134]	2012	Evacuation conditions; hypothetical scenarios
Russo & Chilà [135]	2013	Evacuation conditions; hypothetical scenarios; calibrated parameters
Russo & Chilà [29]	2014	Evacuation, temporal axis, behavioral demand models
Russo & Chilà [142]	2021	Risk reduction; exposure; evacuation; dynamic demand; sequential analysis; transport systems; utility updating

Table 14. International papers.

Authors	Year	Keywords
Taylor & Freeman [127]	2010	Bushfires; Evacuation policy; Road network; Scenario planning; Strategic planning; Models
Tai et al. [130]	2010	Urban safety; shelter; evacuation choice; spatial autocorrelation; Geographic Information System
Xu et al. [136]	2016	Ordered Probit Model; Hurricane Evacuation Prediction
Lovreglio et al. [137]	2019	Wildfire; human behaviour; decision-making; householder; modelling
Bernardini et al. [138]	2019	Human behaviours in emergency; Earthquake evacuation; Educational training; Emergency management; Behavioural design; Urban pedestrians' evacuation
Golshani et al. [139]	2019	No-notice disaster; Evacuation decision; Two-step clustering; Multivariate ordered probit
Calumba et al. [140]	2019	Earthquake evacuation choice model; Multinomial logit regression; Multinomial probit regression, Surigao City; Philippines
Calumba et al. [141]	2021	Earthquake management; evacuation behavior; choice modeling; travel patterns; multicriteria decision making; emerging country
Suwanho et al. [143]	2023	Traffic behavior; evacuation time; flood water evacuation; road network
Polat & Tezcan [144]	2024	Trip decision; binary logit model; discrete choice analysis; transportation models; evacuation; earthquake

3.4.2. Supply

This section lists the reference works in the supply area related to evacuation. In particular, Table 15 shows the works developed in the SICURO project. Table 16 shows the works developed in the RISK project, and Table 17 shows the works developed at an international level.

Table 15. SICURO papers.

Authors	Year	Keywords
Di Gangi & Luongo [145]	2005	Network vulnerability; risk analysis
Di Gangi [146]	2006	Network reliability; vulnerability
Vitetta et al. [147]	2007 (c)	Evacuation; path design; emergency vehicle
Di Gangi & Velonà [148]	2007	Pedestrian simulation; building evacuation, school experimentation
Vitetta & Assumma [149]	2007	Safety; evacuation; refuge area; queue; simulation
Vitetta et al. [150]	2008	Evacuation; cost functions; microscopic models
Di Gangi [151]	2009 (b)	Simulation pedestrian, evacuation building
Polimeni & Vitetta [89]	2012 (a)	Continuous/discrete variables; heuristic approach; vehicle routing
Polimeni [154]	2012	Rescue vehicles; vehicle routing; optimization models
Musolino [156]	2021	Risk; transport system models; supply; evacuation; learning process

Table 16. RISK papers.

Authors	Year	Keywords
Vitetta [157]	2025	Flow fundamental diagram; risk assessment; transport systems

Table 17. International papers.

Authors	Year	Keywords
Dias [152]	2009	Emergency vehicle routing; Traffic signal Preemption; Dynamic path planning; Signal phase selection
Zheng [154]	2014	Evacuation; public transit; Lagrangian relaxation
Swamy [155]	2017	Humanitarian logistics; Disaster operations management; Evacuation modeling; Transit planning; Bus evacuation problem; Simulation modeling

3.4.3. Assignment

This section lists the reference works in the context of evacuation assignments. Table 18 shows the works developed in the SICURO project, and Table 19 shows the individual works on an international scale.

Table 18. SICURO papers.

Authors	Year	Keywords
Russo & Vitetta [158]	2000	Exposure; evacuation; risk
Russo & Vitetta [159]	2003	Transportation planning, emergency conditions, behavioural conditions, user optimum, system optimum.
Vitetta & Velonà [160]	2003	Static assignment, pseudo-dynamic assignment
Musolino & Vitetta [161]	2003	Dynamic Traffic Assignment; microscopic approach; disaggregate analysis; queuing and lane-changing phenomena
Di Gangi et al. [162]	2003	Pseudo dynamic assignment, mesoscopic assignment, microscopic assignment, urban road network
Vitetta et al. [163]	2007 (a)	Evacuation, path design, emergency vehicle.
Vitetta et al. [164]	2007 (b)	Evacuation, microscopic approach, link model

Table 18. Cont.

Authors	Year	Keywords
Di Gangi [166]	2009 (a)	Disaster management; mesoscopic traffic assignment; evacuation
Vitetta et al. [165]	2009	DSS for evacuation planning; supply; demand-supply interaction
Di Gangi & Rindone [167]	2011	Pedestrian simulation; building evacuation, aggregate evacuation time
Di Gangi [168]	2012	Evacuation; path search; pedestrian Network optimization problem; vehicle routing; discrete/continuous variables; genetic algorithm; short-term travel time forecasting
Musolino et al. [169]	2013	Route choice; switching behaviour; day-to-day models; information; evacuation; smart city
Marciànò et al. [171]	2013	Within-day assignment; signal setting; road evacuation; path enumeration.
Polimeni & Vitetta [174]	2014	Cost functions; demand update; constrained gradient algorithm; traffic assignment; route design
Musolino & Vitetta [173]	2014 (a)	Dynamic assignment models; cost functions; path choice; calibration and validation; evacuation; urban area
Musolino & Vitetta [172]	2014 (b)	Network fundamental diagram; urban traffic indicator; signal setting design; dynamic traffic assignment; evacuation conditions
Marciànò et al. [175]	2015	Road transport networks; Signal setting model; Path choice; Dynamic assignment; Urban evacuation
Di Gangi & Polimeni [177]	2017	Path choice; Evacuation; Dynamic traffic assignment
Di Gangi et al. [180]	2022	Dynamic traffic assignment; evacuation; stochastic process; risk assessment

Table 19. International papers.

Authors	Year	Keywords
Liu et al. [176]	2016	dynamic traffic assignment, link flow
Gauthier et al. [178]	2018	dynamic mesoscopic, day to day disruption
Huang et al. [179]	2021	Ant colony optimization (ACO); evacuation; incremental flow assignment (IFA) method; multipath optimization; swarm intelligence
Men et al. [181]	2022	Gaussian type-2 fuzzy variable; multi-crowd congestion-relieved emergency evacuation problem; multi-point diversion evacuation strategy
Zhang et al. [182]	2022	stochastic dynamic traffic assignment; emergency evacuations; equilibrium functions; path choice; logit model.

3.5. e-ICT DTA

The papers that belong to this class are the newest and constitute a niche in what is the literature on risk reduction by exposure reduction.

The works constitute a niche because they deal with the intersection of two particularly advanced segments: the use of e-ICT in transport systems and the use of dynamic multi-

period assignment models, DTA. The models covered in these articles are particularly useful in both the mitigation and preparedness phases [31,34,183–192].

The small number of references in this sub-area does not indicate a complete lack of research, but rather a very early stage of prototyping and technological demonstration. This confirms that the integration of e-ICT with DTA for evacuation is an emerging sector with considerable growth potential.

The following tables show the reference works in the e-ICT field with reference to DTA and evacuation. In particular, Table 20 shows the works developed in the SICURO project. Table 21 shows the works developed in the RISK project, and Table 22 shows the individual works on an international scale.

Table 20. SICURO papers.

Authors	Year	Keywords
De Maio et al. [183]	2013 (a)	Smart city; Intelligent Transportation Systems; path choice; vehicle routing; design models
Chilà et al. [185]	2016	General methodology; intelligent transportation system; urban evacuation planning process; transport models; transport system design; ITS; exposure component; emergency conditions; risk management; evacuation conditions

Table 21. RISK papers.

Authors	Year	Keywords
Di Gangi et al. [187]	2023	Decision support system; emergency management; evacuation; ICT; IoT; risk management; VGI
Musolino [188]	2024	Risk reduction; evacuation planning; transport system models (TSMs); network model in emergency conditions; users updating utilities; emerging information and communication technologies (e-ICTs); urban areas
Russo et al. [34]	2024	Risk reduction; emerging ICT; dynamic demand models; evacuation; smart city
Russo et al. [189]	2025 (b)	Risk; Exposure; Evacuation; Assignment; Transportation System; Information and Communication Technologies

Table 22. International papers.

Authors	Year	Keywords
Stephens et al. [184]	2015	Communication; crisis; disaster; evacuation; ICTs; transportation
Humagain & Sinha [186]	2019	Autonomous vehicles; smart cities; Real time systems; emergency responses
Harpreet & Ramandeep [190]	2025	Automotive Engineering; Machine Learning; Smart Infrastructure; Transport Research; Artificial Intelligence; Transportation Technology; Traffic Engineering
Su et al. [191]	2025	Construction project safety; Blockchain technology; Safety risk monitoring; Evolutionary game; Prospect theory

Table 22. Cont.

Authors	Year	Keywords
Du et al. [192]	2026	Mining cyber-physical systems; Risk assessment; Coordinated recovery network; Emergency response strategies; Resource allocation optimization
Su et al. [31]	2026	-

4. Discussions and Conclusions

The classification of the scientific contributions in the areas identified at the beginning of the work and expanded in Figure 6, namely planning process, training and exercise, Advanced TSMs, and e-ICT DTA, has made it possible to map the panorama of the reference literature on the topic of risk exposure reduction by evacuation.

To conclude the state of the art and provide an insight into the interrelationships between the documents within the corpus, a citation-based network analysis obtained by VOSviewer (Version 1.6.20) is presented on the subset of the corpus indexed by Scopus (149 of the 165 publications), for which the metadata required to construct the network were available. The following diagrams highlight the temporal evolution of the epistemological network for the entire dataset (Figure 7), as well as for the specific sets that present the planning–operational approach (planning and exercise) with the modeling–simulation approach (TSM and DTA), respectively Figure 8 and Figure 9.

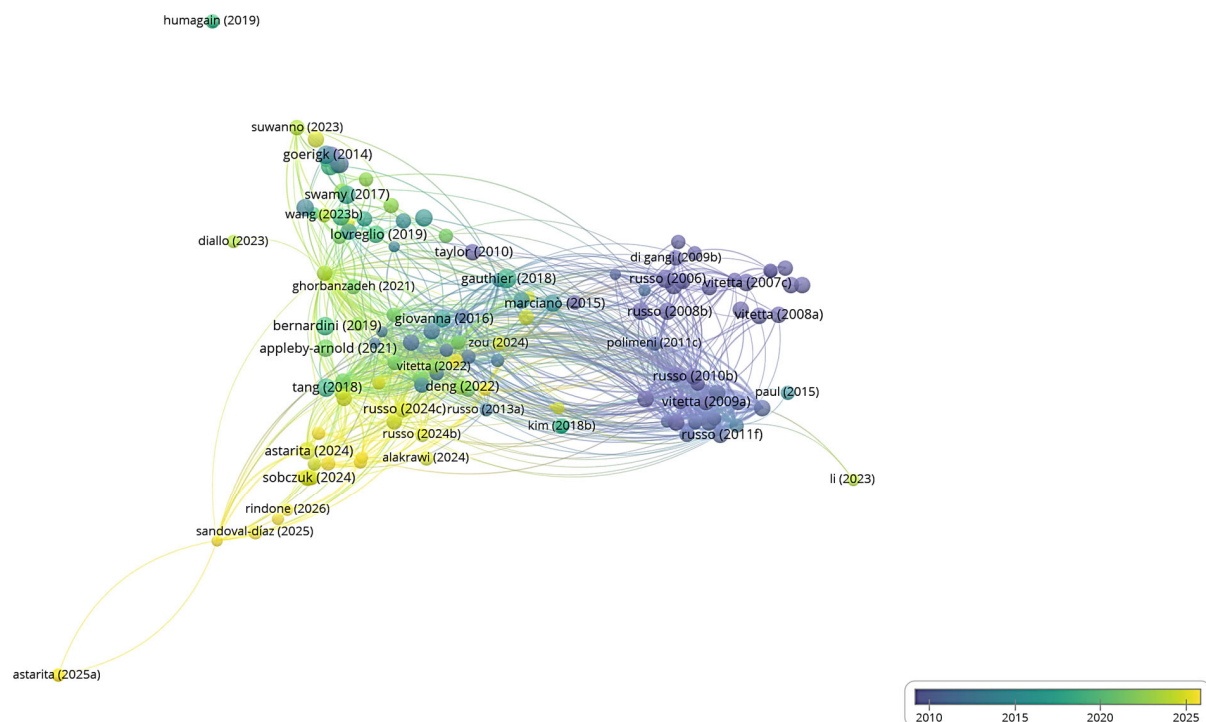


Figure 7. Network analysis on the entire dataset reported in Tables 1–22.

Figure 7 represents the complete citation network. From the density and arrangement of the nodes, it is possible to observe that the clusters are not isolated. In particular, the existence of significant contributions such as Russo and Vitetta (2006) [10], Vitetta et al. (2007b) [163], Tang and Feng (2018) [118], Gauthier et al. (2018) [178], and Astarita et al. (2024) [61] is highlighted.

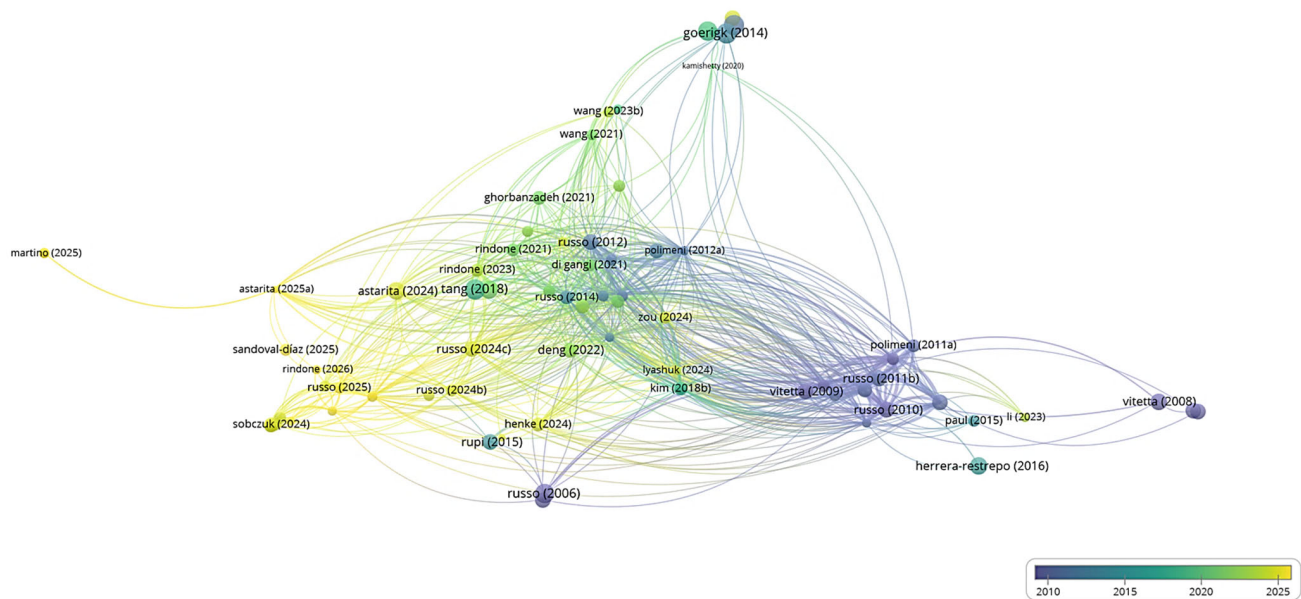


Figure 8. Network analysis on the planning and training/exercise set reported in Tables 1–12.

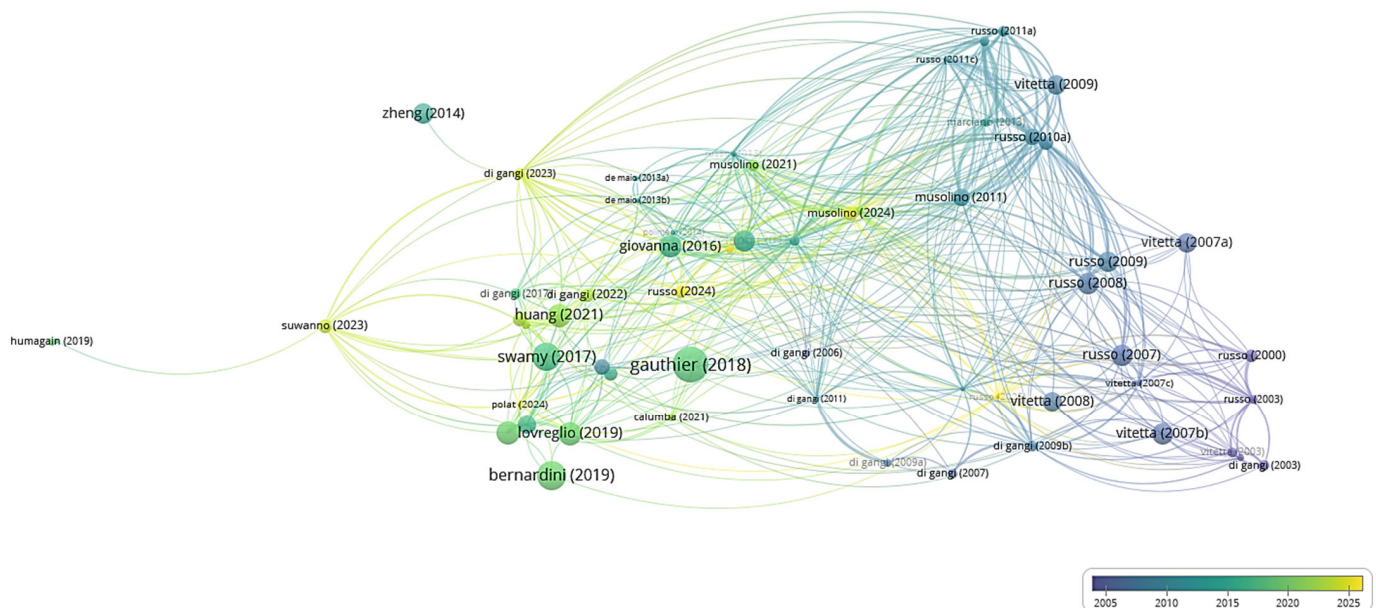


Figure 9. Network analysis on the TSM and DTA set reported in Tables 13–22.

Isolating the documents of the whole relating more to mitigation in the organizational–managerial aspects (Figure 8), the centrality of the contributions of Russo and Vitetta (2006) [10] and Tang and Feng (2018) [118] becomes even more marked. The network also shows an important revival of the research theme in recent years.

The network analysis of the citations for the whole most affected by mitigation in the modeling–simulation aspects, presented in Figure 9, reveals a radically different configuration than that observed for the organizational–management whole. The network is not centralized but looks like a polycentric and densely interconnected network. Notable works include those by Russo and Chilà (2007) [123], Vitetta et al. (2007b) [163], Vitetta (2008) [150], Russo and Rindone (2009 [42]), and, more recently, Xu et al. (2016) [135], Lovreglio et al. (2019) [136] and Musolino (2024) [187].

Figure 10 summarizes the geographical perspective and time evolution of the risk exposure research covered by this study. The diagram combines two essential information dimensions:

- The spatial dimension (clusters per country): each node represents a country from which scientific contributions originate, which is proportional to the volume of publications attributed to that country;
- The temporal dimension (chromatic scale): the color of each node, according to the graduated scale on the side, indicates the average year of publication of the works. The scale goes from blue (oldest average) to yellow (most recent average).

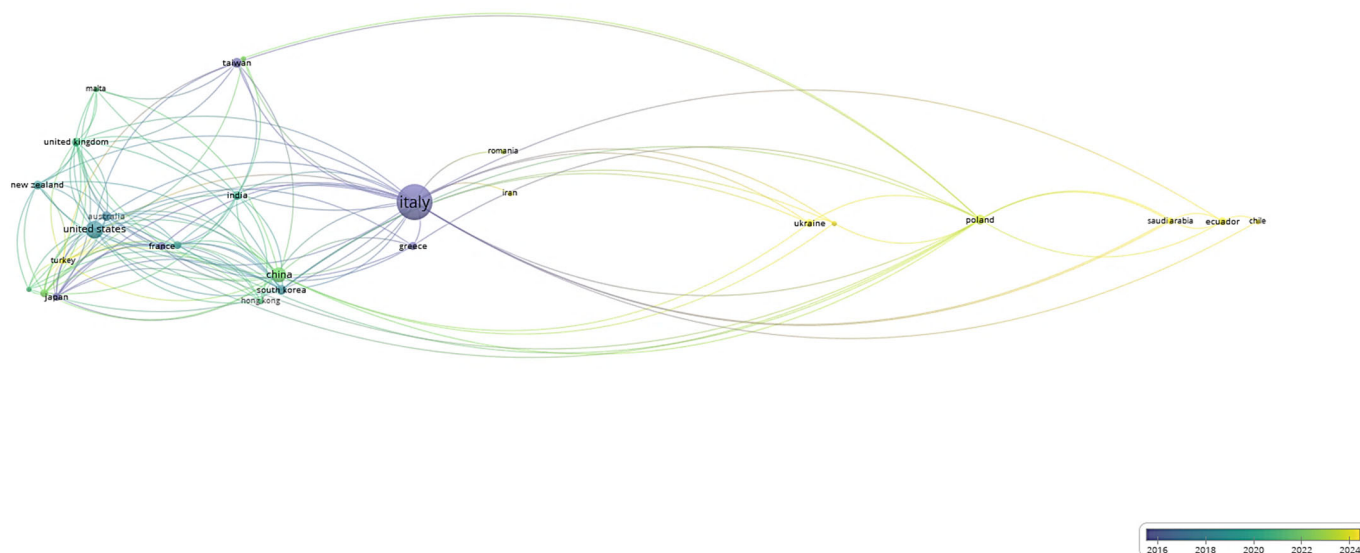


Figure 10. Network analysis of a geographical cluster.

The geographical analysis shown in Figure 10 was carried out using VOSviewer on the subset of the corpus indexed by Scopus (149 of the 165 publications), for which the metadata required to construct the network were available, and covers the corpus as a whole rather than being stratified by macro-region. Italy is the most productive country, in line with the national research projects SICURO and RISK, which form the basis of much of the corpus, followed by the United States and China as the main contributors. A second group of countries, comprising South Korea, Hong Kong, Taiwan, the United Kingdom, New Zealand, India, France, Turkey, Japan and Australia, shows a more moderate volume of publications, whilst a long tail of countries (Poland, France, New Zealand, Japan, Saudi Arabia, Ukraine, Romania, Greece, Iran, Chile, Ecuador and Thailand) each contributes a small number of publications, mostly recent ones.

Figure 11 shows the analysis of the keywords extracted from the titles and abstracts of the scientific papers contained in the entire dataset. This diagram identifies the most recurring terms in the headlines, whose size is proportional to their frequency, and the color, from blue to yellow, represents the average year of publication of the documents in which each term appears. The analysis is divided into three interdependent axes: transport system modeling, risk analysis in emergency conditions and operational planning. The time scale shows an initial emphasis on the concepts of vulnerability and security. The focus has shifted decisively in the more recent literature towards the actions necessary to reduce risk and methodological insights.

From the analyses carried out, some general problems emerge that are useful to recall and highlight. To simplify, in this section, the “risk reduction by reducing exposure to be

obtained by evacuation using transport networks” is summarized as “risk reduction by means of transport networks”.

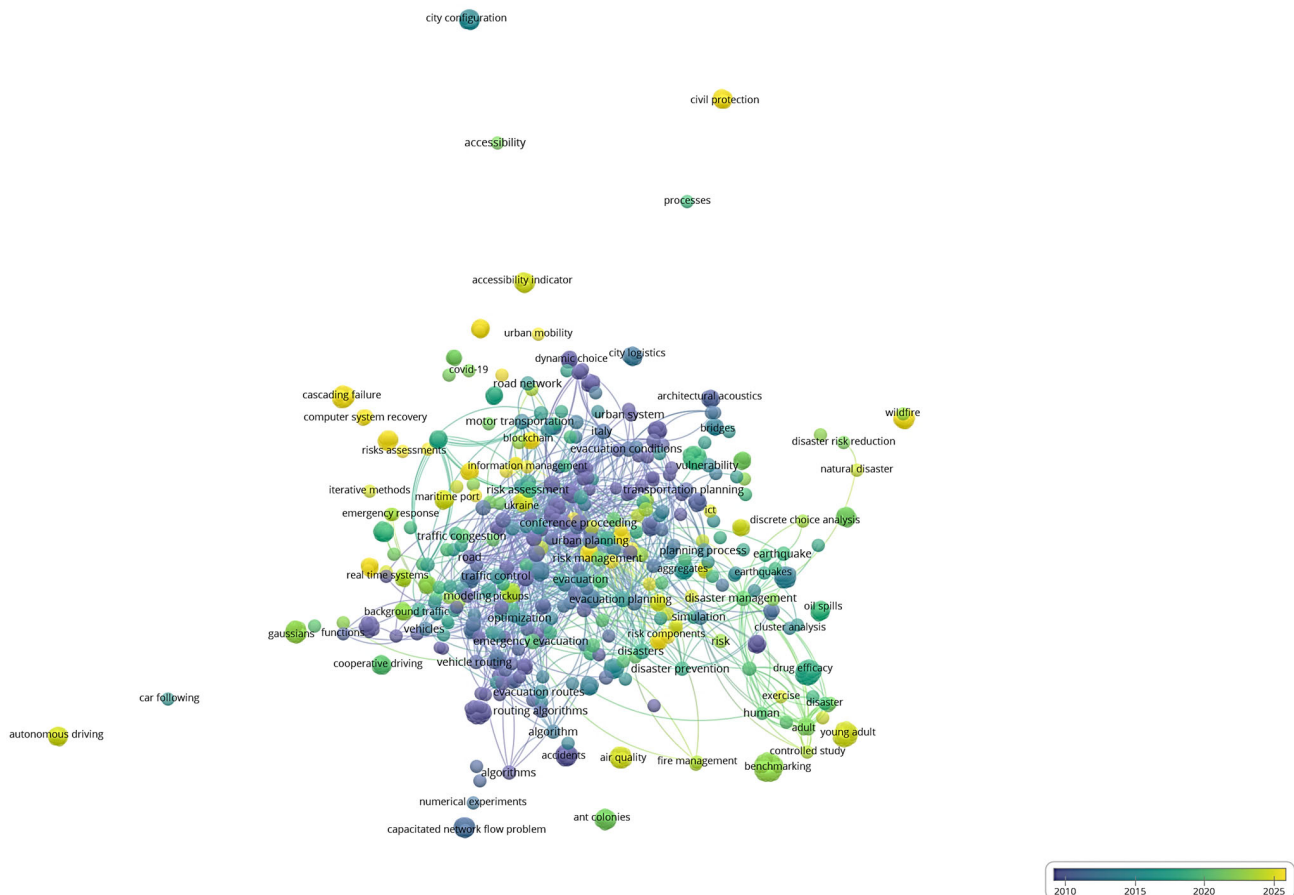


Figure 11. Keyword analysis.

The first problem that emerges is the lack of overall attention given by international scientific research to the problem of exposure and, therefore, to the problem of optimizing evacuation. In the face of an impressive scientific corpus addressed toward the problems of occurrence and vulnerability, which have given rise to various scientific disciplines, exposure to risks and evacuation seem to have been removed from social knowledge and, therefore, from scientific thought.

In the opinion of the authors, the literature on risk reduction through transport networks is extremely limited compared to the problems posed by disasters. In indoor environments, the problem of a forecasting approach to evacuation has begun to arise, but such an approach has not been developed for outdoor environments such as cities or parts thereof, except in small research units. The lack of scientific research is reflected in the international technical literature, which is all organized according to a prescriptive approach. In the face of a highly evolved development of the TSM in ordinary conditions and in the face of a scientific development of the TRA, in particular for dangerous goods, there is a lack of integration of the two research axes in order to produce forecasting models capable of reducing risk through transport networks. There is a complete lack of technical literature that allows evacuation plans to be developed with a forecasting approach.

There is a lack of scientific literature that focuses on social knowledge of risk. The scientific literature, and therefore the technical manuals, seem to be aimed only at hierarchical management organizations, military or civilian, to be activated in crisis conditions. Only FEMA, after New Orleans, has begun to consider the importance of widespread

knowledge as the first factor to reduce exposure and thus save lives, making the best use of transportation networks.

The problems mentioned so far weigh heavily on the death tolls of man-made and natural disasters and, in fact, prevent the pursuit of the sustainability goals defined by the 2030 Agenda, mentioned above. The evidenced problems are present in all countries on an international scale, regardless of the political regimes and the economic and technological development conditions of the different countries.

After this schematic summary of the general “historical” problems, it is useful to recall the problems and challenges that arise today with the advancement of technologies available to users and risk managers. In recent years, in countries that have advanced technologies, the use of ICT in urban areas has developed strongly. Recently, several classes of ICT have been integrated into transport systems to improve and optimize their operation. The set of these classes of ICT, already mature in applications other than transport, but “emerging” in relation to this field of application, is defined as e-ICT.

A problem that emerges from the state of the art analyzed is that of the lack of any technical literature on the use of e-ICT for risk reduction through transport networks. This is a lack that seems particularly serious. In fact, the technical literature is still delayed in the attempt to coordinate emergency telephone numbers between the various countries, demonstrating a considerable delay compared to the ICT technologies available today. Only prototype works developed by niche research units are present in the literature, in the face of the pervasive presence of smartphones. This presence would allow, if well used, to greatly reduce the overall evacuation times through transport networks, improving the choice of safety destinations and the routes to reach them. These reductions are already documented in the prototype studies reported in the literature.

A different and important problem is that relating to training and exercises. Obviously, the best evacuation plan produces zero impact if it has not been publicized and adequate training and exercise activities have not been carried out. This problem can be broken down into two parts: Problem 1, definition of a general structure of training and exercise activities and specification of individual activities and Problem 2, evaluation models of training and exercise activities. For Problem 1, the specific analysis of the available literature allows, first, a synthetic evaluation. The USA has proposed an organic technical literature with a very clear structure of the activities to be carried out for the reduction of risk through transport networks. There are no structures as homogeneous and integrated as those in the other global research hubs, namely Europe–EU and Asia–China. For Problem 2, the analysis of the literature shows a generalized delay worldwide.

Directly related to the last problems enunciated is that of their integration, i.e., the use of e-ICT in training and exercises. This problem still seems to be only enunciated, even if the important advances in technology in the “game” sector would allow us to hypothesize a rapid advancement with the possibility of offering very valid tools even to countries that do not have widespread technologies in smart cities. Some works in the serious game field offer interesting perspectives. e-ICT can make an important contribution to the development of an advanced training and exercise structure and an equally important contribution to the evaluation of training and exercise activities. Also, for this problem, as seen before for the use of e-ICT in disaster conditions, there are only small niches of prototype research.

Each of the problems enunciated so far can, in turn, be analyzed in detail to highlight which are the specific open problems and those on which the research has brought greater results. As seen above, only the general problem of evacuation connected with transport systems, i.e., the possibility of preparing evacuation plans with a forecasting approach that, therefore, goes beyond the traditional prescriptive approach, has had scientific evidence,

i.e., the study to be developed in the “mitigation” phase. In this context, several issues remain open, both in the short term and in the medium-long term.

Short-term actionable problems include:

- structure of demand models under risk conditions and calibration of parameters;
- study of the centrality in supply systems both for access to safe places and for the identification of the most congested nodes in conditions of risk;
- explicit modeling of capacity and capability gains from training and exercise phases, developing quantitative metrics for preparedness effectiveness.

Medium-to-long-term exploratory problems include:

- study of the models of organization of evacuation plans and connections with SUMP (sustainable urban mobility plans);
- formalization of the TRA with the relationship between individual risk and social risk;
- study of the allocation of demand to the supply system in conditions of risk;
- role of e-ICT, individual and collective, present in specific urban areas for the reduction of exposure;
- integration of e-ICT with DTA for dynamic, real-time evacuation management and user information systems;
- Digital Twin-based approaches for evacuation scenario simulation and real-time decision support;
- AI in terms of Large Language Model (LLM) approaches to disaster management and evacuation coordination.

This study has some limitations. First, the ‘snowball forward’ technique depends on the relevance of the initial articles selected and may not capture very recent works that have not yet been cited. Second, the grey literature and sources outside the databases consulted were not systematically included. Third, for part of the corpus, only the abstracts were available for analysis, as the full texts were not open access, which may limit the depth of the classification of these works. Finally, the search was restricted to the English language, which may have excluded relevant contributions in other languages, such as the Chinese one.

The problems that emerged from the state-of-the-art study and are summarized here highlight important gaps in the scientific and technical culture for risk reduction using transport systems. The same problems are, at the same time, important challenges for scientific research and for some operational prototype implementations. The work is, therefore, useful to researchers from various fields who can identify different areas of research on which to operate. At the same time, the work can be useful for the entire business world working on ICT, from large “big tech” corporations to small start-ups working on individual apps. Finally, the work can be useful for political decision-makers at various levels, from local authorities to ministers, to start innovative experiments in the various sectors with sustainable development as a reference.

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