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REVIEW ARTICLE

A Multi-agent Based Evacuation Planning for Disaster Management: A Narrative Review

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Abstract

Many researchers have been shifted towards considering different evacuation planning issues to achieve safe evacuation so that the mortality rate can be minimized. In virtue of rapid exploration in this field, it become stringent to find better agent-based evacuation model for evacuation planning in case of different types of disasters. Moreover, till now, there exists no systematic review of existing agent-based evacuation models which have considered various types of disasters with the corresponding evacuation techniques applied. Taking this into consideration, the present study attempts to address this gap by presenting a narrative review of various existing multi-agent based evacuation models and highlights their taxonomy as well as extensively compares them by illuminating the strategies and simulation platforms used by them along with their relative advantages and disadvantages. The paper also highlights the future research challenges with the aim to foster more research in the realm of finding better evacuation planning strategies to be employed in the agent-based evacuation model for safe evacuation.

1 Introduction

An agent [82] can be defined as "a computer system situated in some environment, capable of taking autonomous action to achieve its design objectives". The environment in which multiple agents communicate to co-ordinate their actions and behavior, results in more coherent systems called Multi-Agent Systems.

Multi-agent System (MAS) [64] *comprises multiple interacting intelligent agents*. Agents in the MAS could all be of the same type (homogeneous) or different types (heterogeneous). Homogenous MAS formulations employ agents that have similar capabilities and are often designed by a same individual. Heterogenous agents on the other hand are usually designed by different individuals and may have different goals.

MAS is used to solve problems [64] that are either difficult for an individual agent to solve or where multiple agents are interacting together to solve it. If the agents are working together to solve a complex problem, they will cooperate or coordinate with each other to achieve the global solution. Coordination is a central theme of interaction in MAS formulations. By efficient coordination, the agents can work together to complete their goals in less time with increased reliability and better resource usage. Therefore, multi-agent systems can provide excellent solutions where there is a need to solve a problem with limited resources and time constraints.

Disaster is a situation due to which sudden chaos arises in the normal routine [39]. Disasters (natural as well as man-made) have been causing huge damages to the infrastructure as well as to human life for a very long time. The time immediately following the disaster needs to be managed efficiently to minimize the damage to the human population in that area. It is almost impossible to predict any kind of natural or man-made disaster so that immediately required assistance is highly unlikely but proper aid afterward can save many human lives. Therefore, it is required that timely actions should be taken to cope up with the situation created by the disaster.

A coordination based multi-agent system [39] for disaster stuck environments is a solution that ensures efficient resource distribution promptly on time. Multi agent-based problem-solving techniques improve the efficiency of the solution by reducing the time taken to perform different

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actions and making better decisions. The performance of a multi-agent system depends upon two important factors i.e., *learning and coordination*. *Learning* focuses on planning and predicting possible future events by maintaining the history of previous results. On the other hand, *Coordination* ensures member agents in MAS co-ordinate with each other to share various available resources to achieve common goals.

Multi-agent systems can be used extensively in disaster-affected areas that are decentralized and involve communication among agents present in the disaster area to make collective, cooperative, and collaborative planning at a large scale that deals with uncertainty and conflicting information during disaster management.It has been acknowledged from various researches performed in the past that many researchers have been shifting towards evacuation planning issues while the occurrence of disaster to achieve safe evacuation in order to decrease the mortality rate during the same. In the same context, this literature review highlights the survey incorporating different agent-based simulation models employed for evacuation planning in disasters.

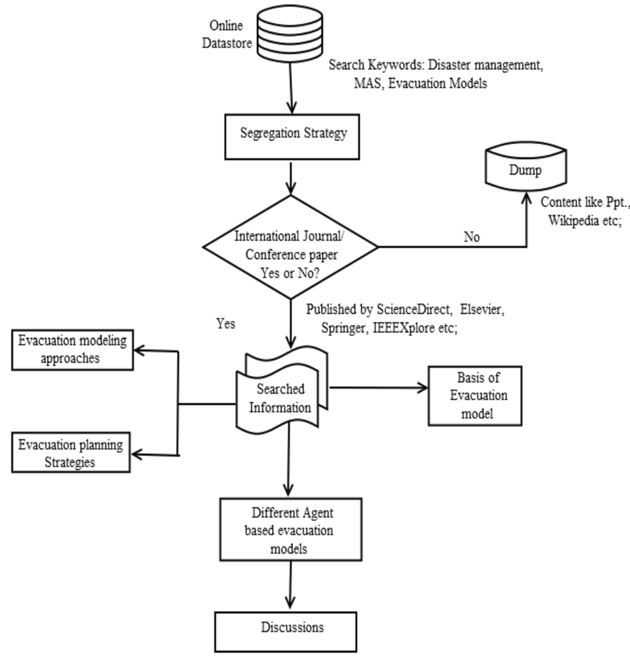

Fig. 1 Graphical Outline of the Present Study

1.1 Motivation of Research

Natural disasters cause devastation in society due to their unpredictable nature. Disasters can cause huge damage to the infrastructure as well as human life for a long time. It has been found that it is extremely difficult to manage the rescue process in disaster-hit areas because there is a lack of coordination and information sharing among different organizations that are working together. Whether the damage is minor or severe, emergency support should be provided within the time for evacuating the crowd. Multi-agent systems have been proposed to efficiently cope with the emergencies such as disasters by performing different actions with help of different agents interacting with each other to minimize the consequences in certain ways.

Therefore, to entirely cover up the knowledge of agent-based evacuation framework, numerous parameters like human behavioral impact, decision making, evacuation time and path choice, travel mode choice, the configuration of required resources, and settlement siting are taken into consideration. It is mandatory to provide the practitioners and researchers up to date state-of-the-art research as well as guide them to figure out relevant studies of their own needs about evacuation parameters based on different agent-based simulation models, their challenges, and different parameters. As a result, this literature review elucidates a meticulous knowledge of all the above-mentioned aspects in a single paper. Specifically, the authors aim at a finer level of granularity in classifying the different agent-based evacuation models concerning various evacuation constraints.

The outline of the present study can be fairly explored from Fig. 1.

1.2 Systematic Review Process

In this subsection, all the phases for conducting this review have been clearly described, which discuss that how the previous research is identified, evaluated, and interpreted concerning a specific topic or an area of interest. Firstly, the research questions are detailed to evaluate whether the objectives of the present study will be achieved or not. Subsequently, the quest approach is formed to maximize the possibility of achieving the relevant research results and also some segregate criteria is formed to include or exclude particular research articles from the review process. Finally, all the collected data is related in a meaningful way and synthesized to give the result of all the research questions.

1.2.1 Research Questions (RQs)

While forming this review, some of the research questions were framed that are listed as below, and in the subsequent sections, the answers to these research questions will be provided.

- RQ 1. What are the existing approaches of evacuation simulation models?
- RQ 2. Why researchers are shifting towards new evacuation strategies?

- RQ 3. What is the basis of evacuation models?
- RQ 4. What are research gaps in existing agent-based models for evacuation?
- RQ 5. What are the various future perspectives that exist in evacuation planning using agent-based simulation models?

1.2.2 Quest Approach (QA)

This review has been performed using a specific procedure so that an unprejudiced and wide range of solutions can be achieved from the literature related to different research questions. The relevant publications in the field of *multi-agent systems, disaster management, evacuation planning strategies, and agent-based models for evacuation* have been leveraged. Moreover, during the review process, the substitute words of each term and abbreviations are extensively incurred for achieving the vast knowledge about each quest area.

1.2.3 Sample Segregation Strategy (SSS)

The Sample Segregation Strategy is necessary to investigate the unsuitability and aptness of existing research articles for addressing the aforementioned formulated research questions. The papers from various publication sources such as IEEE Xplore, Science Direct, Elsevier and Springer have been reviewed and considered. Out of the various reviewed articles, 71 Journal papers, 10 Conference papers, 3 Doctoral Thesis and 7 Book Chapters have been included in this survey. In general, from the total number of papers reviewed and included, 11 were the review papers that discussed methodological approaches for emergency crowd evacuation. The papers included in this review comprised keywords such as multi-agent systems, disaster management, evacuation planning strategies, evacuation modeling approaches and agent-based evacuation models. Whereas, while performing this review, the articles comprising only of keywords such as pre- and post-evacuation criteria have not been taken into consideration.

1.2.4 Data Elicitation and Organization (DEO)

During DEO activity, the systematic approach has been followed to write as well as correlate the elicited information, and further, the suitable and sufficient information has been organized for answering the targeted research questions.

1.2.5 Target Audience

This survey is intended for readers who are interested to acquaint themselves with the techniques used for evacuating in case of disasters and other emergency situations. Different agent-based evacuation models have been studied to analyze those techniques. Also, research-ers with a wide variety of backgrounds in multi-agent systems, disaster management, and simulation modeling can get knowledge by learning how the crowd can be evacuated using procedures that are inspired by the past many decades of research. Furthermore, the experts in evacuation planning strategies may also be lured by the comprehensive description of these techniques in multi-agent systems.

The rest of the paper is organized as follows Sect. 2 engenders the knowledge about different evacuation approaches for simulation modeling. In Sect. 3, numerous issues based on which evacuation is planned in case of no notice of natural calamity have been discussed. Subsequently, Sect. 4 describes the basis of the evacuation model. Further, Sect. 5 throws light upon the different agent-based evacuation models, wher-eas Sect. 6 adds discussions and makes comments on the benchmarks and limitations of the review. In the end, some concluding remarks and future research directions have been presented in Sect. 7.

2 Evacuation Modeling Approaches

Evacuation modeling is the procedure of guiding people to evacuate through the exit(s) when an emergency occurs [8]. These approaches have been devised to ensure the most efficient time for safely evacuating the crowd residing in that particular area. Evacuation modeling provides the potential of designing a system that is capable of simulating complex cases in various types of the environment. The employment of evacuation models in crowded places helps to plan the flow of people for more safe, effective, and ergonomic design formation at an earlier stage of evacuation planning. Some benefits of evacuation modeling are:

- effective layout can be created about the area,
- queuing and congestion can be minimized at the selected points,
- signage can be publicized for a population profile and the position of the objects can be optimized, and
- allowing the successful planning of access, in emergency and normal situations providing security and safety [19].

The evacuation modeling procedure comprises repetitive processes for evacuating the areas at risk, by calculating the required time and the best path to exit from that space. Based on the problem-solving methods, scope and input parameters, various models for evacuation can be developed. The previous researches have mainly considered modeling the evacuation related problems that concentrated on the calculation of evacuation time and were closely related to the research areas like *path finding, operations research,*

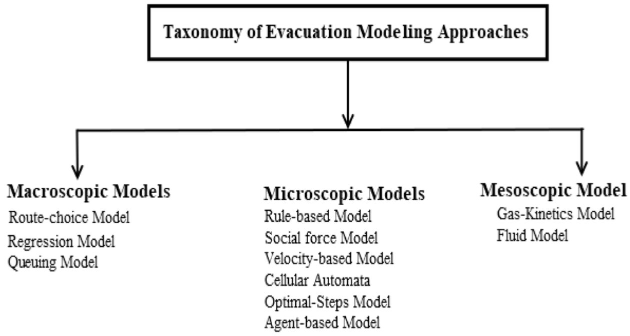

Fig. 2 Different approaches for evacuation modeling

process controlling, network flow, optimization, congestion problems, passing through in large virtual networks, and many other issues [65].

Depending upon the state-of-art and scope, evacuation modeling approaches can be classified as follows, i.e.,*macroscopic, microscopic and mesoscopic models*. These approaches can be used to study the movement of evacuees over time. Figure 2 illustrates the taxonomy of various evacuation modeling approaches being surveyed in this work.

2.1 Macroscopic Models

Macroscopic evacuation models account for evacuation motion as a homogeneous flow [87]. These models abstractly consider the system as a whole and follow a top-down approach in which collective movements of pedestrians have been taken into consideration. In macroscopic models, for the evacuation process, the time has been taken as a decision component required to create good lower limits for the total evacuation time. Various components which have not been taken into account in these models for choosing the exit route are, the behavior of individuals, evacuee's movement and the decision making and communication between evacuees during evacuation. The crowd has been demonstrated in a cooperative manner using various parameters such as spatial density, average velocity, and flow rate about the time and location. These bound factors can help predict existing buildings or to plan the design of new buildings [56]. Most macroscopic models use mathematical or analytical methods that are based on static or dynamic network optimization formulations and some integer programming frameworks to evaluate problems related to evacuating. But both of them cannot provide accurate results as the behavior of each pedestrian impacts the evacuation time [49].

Macroscopic evacuation models mainly depend upon optimization approaches. The main advantage of these models relates to their efficiency and ability for wide-scale crowd simulations. These models explain in a better way the density-flow profiles during the evacuation of the crowd rather than the pedestrians' emergent behavior in a crowd [50]. This constraint is understandable as the macroscopic models follow the aspects of deductive reasoning. On the contrary, emergent behavior arises without the influence of external factors like signals and conventions such as congestion at the small passages and the formation of traffic in the opposite direction of moving flow [38]. Common macroscopic models are: *queuing models* [34], *regression models* [41] and *route-choice models* [25].

Queuing models are used to describe the movement of pedestrians from one network node to another by following the concept of Markov chains [34]. In this model, rooms and doors are represented by nodes and links. Markov chains can be illustrated by combining a set of states implementing transition probabilities [51]. Transitions that involve changing of state are only considered.

Regression models determine the pedestrian's flow under certain conditions using relations between flow parameters that are evaluated statistically [41]. The flow characteristics of pedestrians are connected to physical structures and pathways like corridors, lobbies, stairs, ramps, walkways, and so on.

Route-choice models describe the process of path finding by the pedestrians based upon the utility concepts [25]. The convenient exit is selected by the pedestrian for maximizing the factors like comfort, safety and cost while evacuating the risk area.

2.2 Microscopic Models

Microscopic evacuation models determine the evacuation condition in the best possible way by analyzing various concepts comprehensively [83]. These models follow a bottom-up approach in which evacuees have been described by individual entities having specific characteristics such as age, gender, capability, body structure and moving speed. The microscopic models concentrate on the time-space behavioral details and mobility of pedestrians (i.e., *physical capabilities, changes in the passage, moving speed, different social, physiological and psychological factors*), the interactions and relationships among pedestrians. They portray a detailed description of the individual in context to time-space [31]. The simulation process of large-scale crowds using microscopic models is difficult to perform with traditional single-processor systems as they are computationally intensive. But parallel computing methods can be applied to achieve a solution to this situation. Applying analytical techniques can help in reducing complications of microscopic models. These methods are affordable but are constrained to solve only evacuation issues. As these analytical processes have become more intricate in an evacuation model, it is difficult to study the evacuation process employing them. Moreover, the analytical model is subject to the supposition that the system has come to a steady or equilibrium state so the peak or transient conditions have not been modeled. It is therefore difficult to analyze without evaluating certain aspects that the previous data parameters were enough to define the system.

To develop an effective model, various attributes (depending upon states, cases, events, surroundings, and so on) are required to be examined. To understand the available choices, certain classifications can be used along with these attributes. Zheng et al. [89] indicated seven classes for microscopic modeling approaches which are as follows: *social force models, cellular automata, agent-based models, lattice gas models, fluid-dynamic models depending on the experiments with animals, and game-theoretic models*.Concerning this information,most common microscopic models for evacuation simulation giving preferable results have been discussed, i.e.,*rule-based models* [55], *social forces models* [23],*cellular automata* [13], *velocity-based models* [71], *optimal steps models* [60] and *agent-based models* [57]. The difference between all of these is in terms of space and time quantization. Moreover, for the evacuee's dynamics simulation, similarities and differences of microscopic systems based on scalar fields concept have been determined [59]. The scalar field concept proves to be an effective method in providing a platform for many numerical evaluations in various models and thereby giving an immediate response. But the issue of flexibility, superposition of binary interactions [45], calibration of model attributes [44] are some of its drawbacks. Furthermore, models based on scalar fields concept have been best to use in practical applications whereas they do not represent decision-making and natural motion effectively. Therefore, if some system does not fulfill the criteria of development and there is a need to find an effective model or to design a new model, it becomes important to identify similarities and differences [58].

Rule-based models [55] have been applied in the case of low and medium density crowds for determining the behavior of evacuees. They do not evaluate the acknowledgment and collision detection approaches. They only solve the conservative aspects by using the "wait for rules" (i.e., to enforce ordered crowd behavior in a flocking style for medium density crowds) that gives better results for less dense crowd simulation but has not been able to perform realistic simulations in panic or large-dense crowd situations [52]. These models have also not been able to simulate relationships among individuals because they do not consider the interactions among them during motion. By integrating these models with cognitive models, better realistic evacuee's behaviors for crowd simulation methodologies can be achieved as different behavioral rules can be implemented on crowds or individuals [61].

Social force models [23] examines microscopic evacuee behavior (i.e., path choice behavior, some actions/ movements) with an association to social fields initiated by the individual's social behavior. Social forces like a safe place, tension, pressure, emotion, fear, anxiety, space requirement, grouping, flocking, congestion have been framed, the interactions and results among individuals are evaluated and validated in these models. Social force models, unlike human movement, create particle animation like simulations [52]. They guide researchers to interpret crowd behavior by finding new relationships and creating different mathematical rules in emergent and natural cases. In these models' real simulations can be achieved but by performing various attempts because they are complicated decision-making processes.

Cellular Automata [13] are analytical computational systems proven useful in determining the complexity and non-linear characteristics in various research areas. They have been represented as physical-mathematical systems in which physical quantities take certain distinct values [79]. The main advantage of cellular automata is that it is simple to use, compute and can be implemented with greater efficiency. However, there are few disadvantages like in case of panic situation it affects the study of behaviors (i.e., stepping way, continuous motion, location in continuous space, contact forces) due to the space quantization. In the case of low-density crowd situations, this model gives realistic results as compared to high-density crowd situations where people can move into discrete grids [30].

Optimal Steps model [60] has been designed based upon the rule-based category of cellular automata. It explains the locomotion process which was the limitation of the cellular automata model. In this model, agents do not go from one cell to another rather the movement occurs in continuous space and not just confined to a spatial grid of any kind. Spatial discretization has been considered as the human step. In this model, the decision-making process has been defined as a discrete process of steps by capturing the stepwise motion of an agent and utilizing it as a discretization idea in the simulation. The next location is then found by reducing the potential or by increasing the utility function. Here the next destination function is considered as the navigation field. The speed factor plays an important role since each agent's moving speed depends upon their stride length which involves waiting for the value of the previous move because all calculations for speed depend upon the previous values [60]. Henceforth, an advanced technique of modeling is required that can conform the stride length along with speed [75]. The optimal steps model needs to be examined in a series of procedures where an agent has to move around the barrier in a circle by various degrees. They have the consistency to react to the situation immediately and not to change their direction of movement according to random choice. So, the agents slow down or change the direction slowly [74]. In this model, agents reach the destination using a greedy algorithm. This depends upon the idea of the superposition of scalar fields and local optimization. The scalar field is explained based on utility function which relates every location to a utility value on the plane. The local optimization interpretation is not certain for a description of human decision-making processes as it is an elucidation of utility optimization [70]. The space examined for the optimal next location corresponds to the step length. Thus, in the simulation, one step of an agent is equivalent to a single move of the pedestrian. This procedure helps in attaching the physical process of human moving and dynamic simulations of pedestrians [75].

Velocity-based models [71] have been tested at different time steps that allow them to be discrete in time and space but actually, they are designed in continuous time-space. Generally, discretization has been needed for numerical calculations for simulating a model in a computer. First-order ordinary differential equations have been used to describe velocity which is then computationally combined for getting the agent's location at discrete simulation time steps rather than using rules or transition probabilities for finding further motion steps like in cellular automaton. Velocity-based models can be classified into the *optimal-velocity models* or car-following/car traffic simulations [72], *obstacle-velocity models* used in robotics, animation, and computational science [9], *gradient-navigation models* that simulate pedestrian dynamics based on an ordinary differential equation [12]. The velocity function in velocity-based models has been used by an agent for making the decisions. The difficult point in this model is to determine human movement using these equations as the velocity function is limited.

In *Agent-based models* [57], each evacuee is considered as an autonomous agent. Each agent has its own independent set of attributes that consist of physical and mental parameters, such as gender, mobility, age, weight, and anything that takes part in the speed of the agent and total evacuation time. Multi-agent systems provide realistic solutions for crowd modeling [6] because every individual can act independently by interacting with other agents. The key point of the agent-based crowd model is the attribute set and relationship definitions between different agents. Many researchers worked on modeling more realistic simulation tools using a multi-agent approach, both for indoor and outdoor evacuation [2]. Some of them focused on individual interactions while others tried to consider as many factors as possible in the model. Learning agents have also been created using genetic algorithms, neural networks, and fuzzy logic [62]. They have particular characteristics such as emotions, memory, behavior rules, and decision-making capabilities. The researchers in this work claim that the prototype implementation generates simulation close to the real-world scenarios. Some other studies have focused on particular aspects of an emergency evacuation. Stairs are the most crucial aspect for evacuation as they are the only means to evacuate in high-rises [14]. Stair zones have been divided into smaller areas where probabilities of passing to a neighbor cell have been defined by *benefit matrices*. These matrices have been used to find the transition probabilities. The fatigue factor and decrease in the speed level of individuals in certain cases have also been considered.

2.3 Mesoscopic Models

Mesoscopic models follow a blended approach that consists of the features of both macroscopic and microscopic models [26]. This technique considers the spatial motion of each individual and not the interactions among individuals but it determines the movement as an aggregate flow. These models have not been able to describe the strategy of emergent behavior. They provided the computational savings which were consistent with the view that globally coherent patterns have been dependent upon the local interactions of participants in an entirely parallel and distributed manner. The most common existing mesoscopic models are *gas-kinetic models* [24] and *fluid models* [57].

Gas-kinetic models are almost similar to fluid or gas dynamics that were used to describe crowd density and velocity characteristics, which vary with time by applying the partial differential equations [67].

Fluid models [57] are designed based upon the criteria of determining the analogy between crowd behavior and the motion of the fluid. The system structure consists of nodes in which each node corresponds to the physical components of the building like hallways, rooms, and stairs in the network. Edges represent the pathway between these nodes. In these models, the moving individuals have been modeled as a flow. This shows that it takes time to move from one position to another and flow density measures the number of persons that can use the path at the same time.

The apropos set of pros and cons of all the three aforementioned approaches have been briefly systematized in the form of Table 1.

3 Evacuation Planning Issues

The requirement for convenient evacuation planning strategies has always been a daunting problem when confronted with a large-scale natural disaster. The challenge is to investigate a strategic disaster evacuation planning, *to maximize the number of survivors, to minimize the average evacuation travel time and cost as well to improve the medical care for vulnerable people in the natural disaster* subject to a set of geographical and resource constraints.

Table 1 Brief comparison of macroscopic, microscopic and mesoscopic modeling approaches

Modeling approaches	Pros	Cons
Macroscopic models	Consider evacuation motion as homogeneous flow by using aggregation of the same based on various parameters; Follow top-down approach; Generate good lower bounds for evacuation time;s Capable to simulate wide-scale crowds; describe density-flow profiles during evacuation of the crowd in a better manner.	Use of analytical methods to evaluate evacuation problems; Cannot provide accurate interpretations as they present a macroscopic view of the system; Unable to describe emergent crowd phenomenon.
Microscopic models	Determine evacuation by analyzing different concepts comprehensively; Follow bottom-up approach; Focus on time-space behavior of each evacuee and describe them in the form of a large set of production rules; Use analytical methods to overcome complexity; One of the best available models to be used in practical applications.	Are computationally intensive; Simulating large-crowd scenario is difficult; It is hard to calibrate every minute detail; hence increased complexity; Transient or peak conditions are not modeled.
Mesoscopic models	Combination of macro and microscopic approaches; Describe evacuees and their characteristics in aggregate terms; Provide computational savings.	Unable to determine emergent crowd behavior

To deal with the problem of natural calamities, a modeling framework has been required for evacuation planning of no-notice natural disasters and choosing an effective strategy periodically by using the proposed model. To complete an evacuation against a large-scale natural disaster, such type of framework is required which allows decision-makers to have an insight into *factors* like the *number and location of shelters, allocation and assignment of vehicles, distribution of relief resources, the impact of evacuees behavior, and evacuation time*.

Most of the researchers have focused on designing the models considering the following issues to plan evacuation :

(i) Travel Demand
(ii) Distribution of Relief Resources
(iii) Settlement Sitting
(iv) Transport Mode Choice
(v) Evacuation Behavior.

3.1 Travel Demand

During an evacuation, the households faced several connected decisions that lead to the evacuation trips, which has been the major part of the total evacuation demand. However, the trips extracted from the pre-evacuation preparation tasks that continue for various hours or days are also part of the evacuation demand. Most of the studies haven't even taken into account the traffic that can be generated by these tasks because they have not considered the pre-evacuation activities. The traffic that has been generated as the household purchases (food and fuel etc;) before moving, contributes to the overall congestion [80]. Moreover, preparation tasks [32] play an important role in determining the traffic pattern during evacuation. So, travel which has been considered as a pre-evacuation task is a part of demand representation.

In previous studies, an agent-based system captures household evacuation travel decisions [86] and transforms them into actionable plans. The system has been capable of creating a comprehensive activity-travel plan. The travel behavior during the evacuation process has been represented through econometric and probabilistic models. The system covered the aspect of preparation activities done before evacuation by applying an activity-based approach. The main decisions which have been considered by the system were: whether to move or stay, choice of accommodation type, destination choice after moving, choice of vehicles to use, mode of choice, and departure time choice. It explicitly evaluates the shadow evacuation population. The system resulted in a choice pattern that was dependable upon the previous studies and observations. It also identified the geographical extent and shadow evacuation population ratio.

3.2 Distribution of Relief Resources

Due to the sudden occurrence of a disaster, a quick and efficient response is required to generate plans under various constraints. The affected people require various resources for their daily needs after they have been evacuated. An innovative technique based upon the multi-agent system for resolving distributed delivery scheduling problems has been developed to deliver the goods. The areas have been divided into multiple sub-regions (areas) and each area has further been assigned a delivery scheduling sub-problem to ensure a better response to the crisis [28].

A decision support system combined with an optimization technique has been developed to provide disaster relief coordination between public and private relief organizations. The interaction between both organizations proves to be effective if a delay occurs because of closed roads or in case there is increase in demand. In this system [18], goods have been shipped from transfer to demand points in the affected area, which helps in analyzing the last distribution point for synchronized distribution.

3.3 Settlement Siting

The MAS models have also been designed to solve the problem of site selection for the POC (People of Concern) after the occurrence of a disaster. These models provide a solution by dividing the related tasks into different agents representing decision-makers until the desired solution has been obtained. The system agents use the *hybrid MCDM (Multi-Criteria Decision-making Methods) technique* based upon *FAHP (Fuzzy Analytical Hierarchy Process)* and *RFAD (Fuzzy Axiomatic Design Approach with Risk Factors)*. Three main criteria that have been taken into consideration for evaluating the sites were *the characteristics of land, location and supportive factors as well as social parameters* [15]. *MCDA (Multi-Criteria Decision Analysis)* has also been an effective tool [37] and it has been used in choosing the location of earthquake evacuation shelter [85] and general disaster service area.

3.4 Transport Mode Choice

In most of the previous studies [36], researchers focused upon moving out of the risk area by private vehicles on public lanes. They found that people considered the capacity of the lane as an important factor because when the lane space is less wide it can lead to congestion and people being getting trapped. Usually, people will prefer to evacuate the disaster-hit area by the fastest mode whichever is possible. In developed countries, the majority of people prefer their transport means (such as cars, motor vehicles, hawing trailers and horseboxes). On the other hand, people who are not owning any vehicle or older people living alone use public community transport or take a lift from other people. Some people also evacuated by walking from risk zones. In countries like Japan, many people chose a bicycle as means of escaping tsunamis [68]. But, the choice of this mode can prove to be dangerous at times.

Table 2 The operational behavior of evacuee for another agent in the system [40]

Operation	Observation
Evacuation	Planning and organised
Flight	Random evacuation
Sideration	Inability to respond
Search relatives	Parents, children, wife, etc;
Return home	Feel safe at present places and stay there
Assist others	The agent becomes representative
Antisocial behavior	Panic, looting, etc;

3.5 Evacuation Behavior

Evacuation behavior is defined by a set of actions and attitudes of individuals during evacuation motion [16]. They include attitude towards the environment and other people. While formulating the evacuation plans, there are various interrelated behavioral concerns. Various evacuation models [48] conceptualize the behavior of individuals at the time of evacuation based upon the considerations such as *deciding on whether to evacuate or not, departure time choice, and destination choice*. Table 2 illustrates the actions assumed by an individual regarding another individual when they become aware of an emergency.

The MAS framework [50] has been created for showing human and social behavior during an emergency evacuation. The behavior of the crowd during an evacuation has been studied from the three aspects— *single, interaction among individuals, and clusters*. The prototype of multi-agent based framework has been developed for demonstration of exit analysis. Human behavior (competitive, queuing and herding) has been modeled by the system through simulation at the macroscopic level in an artificial environment. A perception-action model has been adopted in which agents continuously assess the nearby environment and make decisions. A test occupant has been employed to find out what evacuation patterns of design have been followed from the perspective of[1] egress. Then by exploring different geometric configurations and re-arranging exit signs, a designer can modify the plan to alleviate congested areas and to provide an efficient egress route.

4 Basis of Evacuation Model

Developing a framework for emergency evacuation is a complex process. The evacuation model has been designed considering different perspectives as discussed in the

[1] the action of moving out of the place in case of emergency

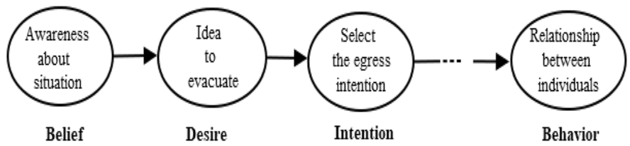

Fig. 3 Evacuation Behavior determined by BDI Relationship

previous section. In this section, the technique of building an evacuation model based upon MAS theory has been discussed. Usually, it has been designed by analyzing *the evacuee's psychological, physical and behavioral characteristics*. With multi-agent theory, the system has been built following bottom to top approach where each individual is represented as an BDI(Belief-Desire-Intention) agent. The reasons for choosing a BDI architecture [1] for presenting the basis of evacuation model are :

- BDI paradigm is based on the concept of *folk or commonsense* technology which can naturally predict the behavior and mental states of individuals.
- BDI paradigm offers a more crisp description making agent-based models simpler and easier to understand for modellers and end-users.
- BDI paradigm can be implemented using a wide variety of multi-agent programming platforms like PRS(Procedure Reasoning System,Agent Speak(L), JASON, JAM, dMARS, JACK etc.).

In case of an emergency, the status of the individual is controlled by the belief to live and the evacuee's behavior [22] will be dominated by common thought.

4.1 Belief, Desire and Intention (BDI) Relationship

There is a great impact of an environment [22] in case of an emergency on the evacuee's mind. In such a condition, the mental pressure increases whereas consciousness decreases. The *interaction* among people also varies from *independent relation to competition, cooperation, and sometimes opposing*. The evacuee tends to follow the route chosen by the crowd. It moves to the nearby egress under the control of belief to save their life. The major *obstructions while evacuating* are the *structure* and *other evacuees*. So, the evacuee requires to obtain the data of these hindrances and then by analyzing that data, it can decide to choose the best path to exit. The behavior of evacuees has always been dominated by *Belief, Desire and Intention (BDI)* relationship during the evacuation process. Figure 3, shows how the BDI relationship determines the behavior of evacuees during evacuation.

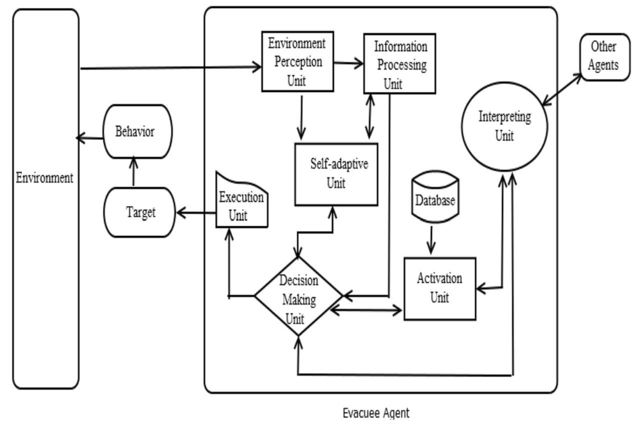

Fig. 4 Agent structure representing an Evacuee

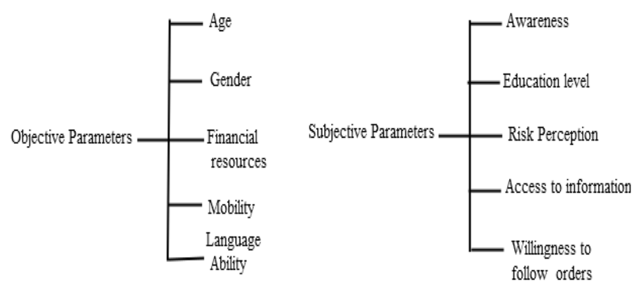

Fig. 5 Classification of individual agent parameters

4.2 Structure of BDI Agent

BDI relationship [22] describes the *behavior and psychological* tasks for an agent, whereas it can't make decision tasks for it. It's just a concept for explaining the awareness of the agent about a particular situation. To construct an agent-based system for an evacuee depending upon the target, a relationship set up has been needed to map the BDI relationship to the behavior of an agent.

In the evacuation process, each individual has a target. It can be the egress of structure or to select a location to reach in the next move. In Fig. 4, the structure of an evacuee agent has been illustrated. Whether or not the evacuee possesses the knowledge of the target, it must need to be aware of the other agents and structure. Each unit corresponds to a condition. The behavior of evacuees depends upon different conditions and situations. Evacuee requires obtaining the right information [84] about the surroundings and then make a move.

Various agent parameters that have been taken into account while considering the evacuation process can be categorized as *objective and subjective parameters* respectively [40]. These parameters can be described using Fig. 5.

4.2.1 Different Types of Agents Functioning in the Evacuation System

1. *Disaster Control Agent* The disaster control agent [84] constitutes the main part of the disaster planning system. It comprises the database, resources, knowledge specialists and managers. Whenever a disaster occurs, first of all, the information regarding the situation is communicated to the control agent by some means for taking control over it. Regarding the given details, the control agent initializes the database which incorporates initial plans and cases, taking the recommendation of specialists and optimizes different facilities of the department. And then it accomplishes immediate action plans by executing the goals and tasks for various agents involved in the system.
2. *Unit agent* All agents perform different actions during various stages of a disaster. On receiving the information to accomplish certain tasks and goals from the control agent, the unit agent [84] formulates its ideas by interacting with the environment and provides the operational information to the control agent for executing the tasks.
3. *Target agent* The target agent [84] can be an individual, cluster, area, or corporation as a whole. The target agent sends information to the control agent for relief resources supply, whenever it is affected by the disaster until the rescue agent arrives. Moreover, whenever the rescue agent comes for help, it must acknowledge the control agent of its arrival and performs required actions to manage the relief work at the targeted destination.
4. *Rescue agent* The Rescue agent [84] consists of different rescue teams from different agents, sent by the unit agents according to the goals and information provided to them by the control agent. The rescue agent takes action as per the situation and then gives feedback to the unit agent regarding the relief operations performed at the operational site.
5. *Interacting agent* The interacting agents are mainly Media, the Internet and the Telephone. The interacting agent [84] acts as a bridge between different agents for transmitting the information. It ensures the flow of information in the system without a communication breakdown.

The scenario of different agents residing in MAS based structure that can be deployed during an emergency has been illustrated in Fig. 6.

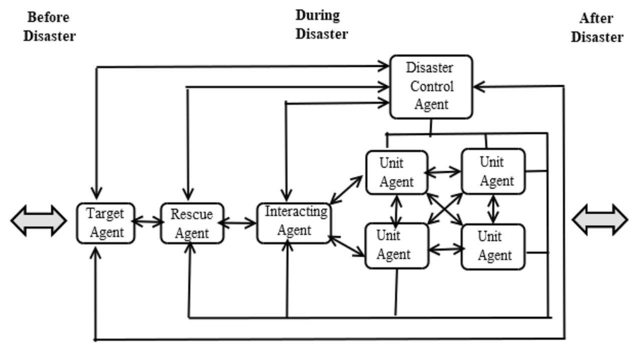

Fig. 6 MAS based system structure used for disaster management

4.3 Evacuee Sensor and Actuator

Sensors and Actuators [22] are the important components of an agent structure that need to be described. During an evacuation, the evacuee's eye has been considered an important sensor and the body parts, especially the legs and feet have been considered as the actuators of the evacuee. In an agent, the behavior structure can be generalized by the movement of the evacuee and then an agent needs to decide the direction and speed of motion. Some of the information collected by the sensor is required to reach the target and the other may not be of any use, so the rest needs to be deleted. The rule followed is:

if (evacuee can analyze the behavior before the possible move up to certain steps)
then
it can store information within this distance.
else
it stores information within the next move only.

5 Agent-Based Evacuation Models

The majority of research papers on agent-based evacuation models and frameworks which were reviewed in the present study can be classified into four types of models according to modeling techniques/strategies used in them :

(i) *DSS(Decision Support System) Based Evacuation Frameworks*
(ii) *Evacuee Behavior Based Evacuation Frameworks*
(iii) *GIS (Geographic Information System) Evacuation Models*
(iv) *Social-Force Model Based Evacuation Frameworks*

This section presents all the reviewed works according to the aforementioned classification.

5.1 Decision Support System Based Evacuation Frameworks

Silva and Eglese [10] developed a prototype of a *Spatial Decision Support System (SDSS)* by linking *Geographical*

Information System (GIS) with the designed simulation system for simulation process execution during evacuation. SDSS has been designed with the purpose to provide an interactive simulator having a graphics facility that will premise for doing experimentation with procedures by giving instant feedback. This system can be helpful to emergency planners during different vulnerable conditions for experimenting with emergency evacuation plans rather than for real-time emergency management use. Mainly, it described the concept of problems that can be faced while designing this type of SDSS to form a proper integration link interface between geographical information system and simulation model. The performed research combined two fields, simulation modeling and spatial technologies to develop a system that can integrate capabilities of both to help in the disaster preparedness process.

Ren et al. [54] presented an Agent-Based Modeling and Simulation framework for crowd evacuation in case of emergency due to an area under fire. Rather than using traditional modeling, different types of agent attributes have been designed for modeling. The simulations have been iterated to investigate the attributes that govern the characteristics of the people. Various simulations have been conducted to analyze the impact of different agent attributes. The results showed how to reduce the effects of such situations thereby providing an optimal escape strategy.

Shi et al. [63] designed an AgenT based Evacuation simulation model called *AIEva* which has been created using a mathematical and physical model. By using rule reasoning and numerical calculations, an agent-based program has been created for simulating the situation of the evacuation process in large public buildings using different scenarios. This model includes the *Spatial Environment Model (SEM)* and *Agent Decision Model (ADM)*. SEM represents the environment of the building during a fire at each time step and it includes building layout information and fire field information. AIEva uses the fire dynamics simulator model to evaluate data about the fire field at each time step. On the other hand, ADM has been constructed as a representation of occupants where agents make decisions regarding behavior and find for respective rules with the change of environment to adjust themselves. A simulation experiment has been conducted considering the Beijing Olympic games stadium evacuation process using a computer simulation program. The spread of smoke and fire can be determined by simulation. It has been observed from results that the system can reflect the behavior of the group, flow density, and congestion while evacuating large buildings. The simulation considered environmental elements like frame and fires but some inherent human qualities have also been considered.

Zhang and Ukkusuri [88] proposed an agent-based hurricane evacuation model which investigated the relationship between evacuees during the evacuation. Here, two types of agents have been classified i.e.,*greedy and normal agents*. Action rules for the agents have been formulated depending upon their behavior during evacuation. The greedy agents choose among the least congested and shortest path whereas the normal agents move over the shortest path towards the desired location. The experiments have been conducted over various case scenarios to test the behavior of agents on the network. The results of this work have been analyzed which shows that sometimes when the number of greedy agents increases, they make evacuation in a system ineffective but in certain cases, the evacuation time decreases as they reduce the congestion by providing the alternative path.

Madireddy et al. [35] developed a control strategy, throttling to test a novel traffic control using an agent-based evacuation model . Throttling has been implemented in real-time which works by temporarily stopping the traffic flow over the lane where congestion level reaches an upper threshold and sending the traffic over it when its congestion level falls below a lower threshold value. This approach results in a reduction of total evacuation time by preventing the road segment to get congested. In this model, traffic has been modeled at a single-vehicle level and vehicles have been considered as intelligent agents that have to carry evacuees to the destination following a certain set of rules. The effectiveness of throttling has been investigated on small test networks and Sioux falls road networks and it has been observed that the system performance in both these networks has been improved. Moreover, it was found that for both contraflow and throttling the total evacuation time was comparable to a traffic control strategy.

Manley and Kim [38] presented an agent-based microscopic simulation model to design and test a decision support system. The model has been developed to safely evacuate individuals with disabilities during an emergency. The study examined various evacuation strategies to evacuate people with disabilities so that they need not wait in shelters. The proposed work also determines the effect of building evacuation environment and other pedestrians' densities on evacuation speed and behavior of those people. The result of the study has been beneficial to emergency management practitioners to evacuate a greater number of people with disabilities in a safe and timely manner.

Songchitruksa et al. [66] described the quantitative evaluation of evacuation strategies using *DynusT, the Dynamic Traffic Assignment Model*. After the hurricane experience, Texas DOT (Department of Transportation) decided to employ a new approach, *evaculane*. The purpose of evaculane was to maximize traffic along key evacuation routes and to avoid the need for contraflow operation if possible. In this work, evacuation strategies and current network type is assessed to determine if it would be able to accommodate the changing demands of a hurricane while evacuating. The evaluation results demonstrated the effects of different evacuation strategies ranging from base configuration to full-scale contraflow with evaculanes implemented on CF (ContraFlow) and normal lanes. The results have shown that the evacuation travel time in the whole network will be on average 30 percent lower than the time-examined during hurricane Rita's evacuation. Moreover, it has been indicated that the evaculane strategy saved up to 2 to 5 percent average travel time in comparison when it was deployed with partial Contraflow (CF) (when evacuation travel time was reduced up to 5 to 7 percent).

Wagner and Agrawal [76] presented an agent-based decision support system for simulation of crowd evacuation in case of fire specifically for places used in the gathering of the crowd. The system aimed at testing different scenarios by replicating the concert venue. The system then acted as a decision support tool for the planning and preparedness phase of emergency management for fire disasters at concert venues. The prototype has been designed basically for emergency managers, police, or any other administration dealing with the mitigation planning for fire disasters at concert venues.

Wang et al. [77] presented a near-field multi-modal tsunami evacuation through agent-based modeling. The motive of researchers has been to determine how changes in decision time and transport mode choice affect mortality rate of people living in coastal areas. The results of this work showed that milling time and changes in it have been correlated with variation in walking speed of evacuee, mortality rate and the vertical evacuation structures. If a large number of evacuees use automobiles to evacuate, then the mortality rate increases as well because of increase in congestion and bottlenecks.

Mostafizi et al. [43] presented a framework to analyze the effect of different behaviors exhibited by individuals on life safety during an evacuation in case of a tsunami. The aim had been to find how *survival rate* has been affected by *transport mode choice, milling time and critical parameters* involved in an evacuation. It has been determined that evacuation mode choice strongly and non-linearly influenced the expected number of casualties and increased involvement of vehicles leading to congestion and bottlenecks. Henceforth, this in turn increased the mortality rate. Moreover, the mortality rate has been related to milling time and it varies with the average walking speed of the crowd. The disaster managers, local officers and state agencies have benefited from the decision-making process for making efficient plans to evacuate people for increasing life safety and community resilience.

Delcea and Cotfas [11] created an agent-based simulation modeling for a classroom having two exits to increase awareness among pupils on how to react to evacuation situations. In this model, firstly, classrooms with different configurations have been implemented and based upon selected criteria, the pupil was allowed to capture real-time events to watch the way agents were making evacuation decisions. Secondly, some new evacuation decisions have been employed to summarize the reaction of pupils. Later, results have been collected from both phases and it has been determined that implementing the model in NetLogo was more advantageous in minimizing differences between pupils and creating awareness among the same about reacting in emergencies.

5.2 Evacuee Behavior Based Evacuation Frameworks

Chen et al. [7] summarized the attempts to be made to deal with the extraordinary conditions like challenging evacuation route hazard and the vulnerability that occurred in the Florida Keys because of the hurricane. The proposed study determined the minimum time to be taken to clear the evacuees from a given area in advance of the hurricane. And, if the hurricane causes landfall, how many evacuees can be accommodated in case of flooded routes. An agent-based modeling approach has been used to simulate evacuation dynamics that demonstrate driver behavior and actual traffic flow in an evacuation. The emergency managers and planners can acquire information for devising evacuation plans and can help reduce risks to the community. Also, from the simulation results managers and planners can get information about clearance time to update evacuation procedures and assess different available evacuation options.

Pan et al. [50] presented a framework created using the multi-agent system for showing human-social behavior during an emergency evacuation. The proposed system modeled *competitive, queuing and herding* types of human behaviors. In this study, a perception-action model has been adopted, in which agents continuously assess the nearby environment and make decisions based upon the decision model. To facilitate egress analysis for a building structure, an example has been demonstrated in which a test occupant has been employed to find various evacuation patterns of design for evacuation purposes. Later on, by exploring different geometric configurations and re-arranging exit signs, a designer can modify a plan to eliminate congested paths for providing a better egress route.

Wolshon et al. [81] summarized methods and results from various projects in which the TRANSIMS agent-based traffic simulation system has been employed to estimate and evaluate the traffic circumstances associated with different threat conditions. Various approaches of traffic management that can facilitate the mass emergency movement of traffic across the multi-state region of the U.S have also been described. This work also highlights connected efforts to mitigate issues of modeling at this state, including the ability to check output results of the model and to assess the effects of traffic management and policy on a regional level.

Tan et al. [69] presented an agent-based evacuation model for building in which the evacuation behavior of an individual has been simulated for the different knowledge levels of the internal structure of the building. This model determined the spatial accessibility, which can be changed by activating the fire safety facilities. The building environment has been demonstrated at a macro-level by semantic model, where connectivity between internal spaces, is updated in contrast to the state of fire safety facilities. Whereas, a grid-based representation has been modeled at the micro-level to facilitate the movement of agents within the internal space. The model can determine the evacuation efficiency by evaluating spatial change impact on it, which in turn depends upon the fire safety facilities position and the evacuee's knowledge level. So, it provides the basis for management of evacuation and describing suggestions for designing better building structures and installing fire safety facilities. Using the prototype of the proposed model, different evacuation simulations have been performed for a cluster of evacuees having different knowledge levels using unique and disparate fire scenarios.

Liu et al. [33] presented a framework to analyze the dynamic impact of building destruction on the evacuation process by combining models for buildings and human behavior. The framework combined different modeling aspects for determining the impact of dynamically deteriorating environment and interactions on the behavior of individuals while evacuating them from the building. By using different measures associated with egress time and exit flow rates, it can be unveiled that the proposed model can recommend how to upgrade building structure for improved evacuation strategies.

Ahn et al. [3] revealed the scenario of indoor evacuation using an agent-based simulation model. The observation has been made depending upon the varying width size of exits. Three different cases were observed in the study to evaluate evacuation time differences. The different number of agents and varying exit width were considered in each case. As a result, it was found that an increase in total evacuation time occurred due to human conflict as some people were aware of the exit doors location and size whereas others were not. Thus, the spatial factors of the environment play an important role in determining evacuation time during the emergency evacuation process. It can be concluded from the presented study that while building a new complex structure and designing its interior and exit area the thickly-populated area must be taken into account.

Kaserekaa et al. [29] proposed an agent-based model that enabled simulation and modeling of people evacuating the building in case of fire. The performance of the proposed model can be evaluated depending upon the evaluation of the number of survivors considering different parameters. A case study for simulation of Kinshasa supermarket's building has been performed and it was seen that it can be implemented for various buildings without applying many variations.

Poulas et al. [53] aimed to evacuate the students and staff of K-12 schools situated in the tsunami inundation region of chile. This study utilizes the 08-A drill with which the system has been validated. Firstly, the conceptual framework of the agent-based system used to simulate the evacuation in a school has been described. Afterwards, the instrumentation, building structure, analysis of system and evaluation of data collected during the drilling process has been shown. The model validation has been done depending upon the outcomes of the drill which depends upon velocities and flow rates. Finally, the effect of different parameters adopted by physical attributes has been evaluated based on the simulation results. The simulations showed the movement of agents and have been validated through the analysis of videotapes of real events.

Yuksel [87] developed an agent-based evacuation simulation model to determine the movement of pedestrians and the learning process while in an emergency evacuation situation using *(NEAT) NeuroEvolution of Augmenting topologies*. Using genetic algorithms (GAs), the NEAT methodology can further evolve into artificial neural networks (ANNs). The model helps agents to evaluate evacuation time for areas or buildings at high risk. The proposed system works by identifying the most suitable fitness function for agents that can understand the best possible way to change and improve behaviors.

Zhu et al. [90] proposed an agent-based model combined with a well-calibrated evacuation behavior model and agent-based simulation model framed in MATSim in the context of a hurricane evacuation. Depending upon empirical demographic data, statistically robust discrete choice models have been created. After that, Monte-Carlo Markov Chain (MCMC) methods have be-en evaluated to demonstrate the propensity of evacuation destination preference. An evacuation scene has been designed using the MATSim tool. The results of this research showed that evacuation speed reduces as the background traffic increases, which may in turn affect evacuation efficiency in real events.

Mostafizi et al. [42] presented an agent- based Tsunami evacuation model to adhere to the issue of choosing vertical tsunami evacuation shelter location and vertical evacuation behavior. To evaluate the effectiveness of *vertical evacuation shelter (VES)*, the resultant mortality rate in the case of different vertical evacuation shelter locations has been considered as the main scenario. The factors determined in the scenario were *average walking speed, minimum milling time and the percentage of people who took into consideration the vertical evacuation*. The mortality rate decreases if people consider vertical evacuation. The outcomes of this study have shown that evacuation efficiency has been affected by various factors, i.e., tsunami inundation, location of shelters, expected population distribution, site topography, risk community's physical and psychological capabilities, and behavior of people towards vertical evacuation.

Nakanishi et al. [48] addressed the problem of evacuating older people in a flood situation. A case study using an agent-based simulation model has been developed to predict the behavior of older people during heavy rain. Evacuation procedures and their protocols have been discussed in this work. The proposed system has been evaluated based upon the estimated evacuation times considering six different scenarios. The results have shown that older people do not move in case the shelters are at a far distance when it is dark and they do not have the confidence to drive in heavy rain. At that time, older and elderly people consider it safe to stay in shelters situated within their range of walking distance. Along with the discussion of challenges faced by older people in managing their requirements for moving from one location to another, recommendations for the local government have also been detailed.

Sahin et al. [57] proposed a multi-agent system that combines fuzzy logic to predict human behavior during the evacuation process. Based upon the experiments conducted in this work, it has been observed that the system can simulate the observed information and various issues like arching, herding, and clogging during evacuation. The effect of exit width and density of crowd over evacuation time has been determined. Later, the developed system has been combined with the emergency detection system, which utilizes social media messages to find emergencies at different places. By analyzing such messages, emergency evacuation activities can be performed immediately which can help minimize casualties.

Wang et al. [78] proposed an agent-based tsunami evacuation model that simulated uncertainties in seismic damages to all connections in the transportation network as well as other evacuation aspects. The multi-modal evacuation was considered in which pedestrian-vehicle interaction was explicitly modeled by dynamic traffic stage transition. Besides, walking speed variability, pedestrian speed adjustment, and car speed adjustment were also incorporated in the model to allow for more realistic evacuation simulation. Moreover, various population sizes are used to model population motion and its effect on tsunami evacuation risk. The proposed model is applied within a simulation-based framework to assess the tsunami evacuation risk assessment for Seaside, Oregon.

Barnes et al. presented agent-based modeling (ABM) [5] framework incorporating robust models of human behavior, to help management professionals develop and test their contingency plans for emergency scenarios. The focus has been on creating a macro-scale evacuation ABM for a case study area, to assess whether the inclusion of varied population characteristics and group behaviors affect evacuation time. This research has found that by enhancing the representation of human behavior, more accurate predictions of evacuation time can be produced. It was determined that without the inclusion of adequate population characteristics, the evacuation model will produce misleading evacuation times. And, which may result in knock-on effects, such as a significant increase in fatalities, or injuries as populations cannot leave their homes to a place of safety in the expected time.

Hassanpour et al. [21] introduced a prototype of an agent-based model using the affordance concept to simulate the decision-making process during an evacuation. The proposed approach was tested to model the behavior of evacuees in a platform of a subway station through both normal and emergency situations. The results of the test including the evacuation time and flows toward different scenarios showed that the model can work properly. The proposed approach can generate a useful tool for designers to describe pedestrian movement behavior in their building designs.

Zia et al. [91] proposed the model of extended social influence, along with incorporating technological influence within the social influence and analyzing its effect on evacuation efficiency. The research focuses on the question of rationality vs. emotionalism of individuals in a social context by mainly considering the modeling of local interactions. This concept is well researched in psychological, economic, and social domains but relatively less explored in the domain of modeling and simulating evacuation scenarios.

5.3 Geographic Information System Based Evacuation Models

Uno and Kashiyama [73] presented a multi-agent simulation system for evacuation during a disaster considering geographical information. The proposed system consists of three parts, *the analysis of evacuation using the multi-agent model, the modeling for land and buildings using GIS data and the visualization for numerical results using virtual reality technique*. It has been possible by using this system to evaluate the damage to individuals along with the structural damage through the introduction of a numerical solver. Additionally, in this work, the evacuation model based on the gravity model has been employed. The appropriate evacuation route has been investigated by simulation and Dijkstra's algorithm has been used to obtain the shortest route for the evacuee. The results of evacuation are visualised using 3D CG image and animation using VR so that user can understand the emotional situation of the evacuee.

Edara et al. [17] focused on traffic modeling in large-scale hurricane evacuation networks. In this work, a large network of ten cities has been modeled and the following research objectives have been achieved, namely (i) to estimate total evacuation time (ii) to find congestion, major bottlenecks and other vulnerabilities in a network (iii) to evaluate traffic performance of evacuation routes (iv) to recommend changes in a traffic control plan for improving the performance of traffic. It has been concluded by the authors that for large networks, it is not a better option to perform coding manually and GIS maps have been needed to create a base road network and then find time to match between two actual road geometrics.

Na and Banerjee [46] designed ABDES evacuation model which depends upon embedded *Geographical Information System (GIS)* module for finding a solution to evacuation problem in a network and to determine the allocation of evacuation vehicles, location of the shelters, assignment of evacuees and distribution of medical resources. The proposed study solved two purposes. Firstly, an agent-based discrete event simulation approach has been used for determining evacuation plans for patients with different emergencies and multiple types of vehicles for carrying them. Secondly, the GIS technique has been integrated for a more realistic evacuation model. One of the challenges was to find an evacuation policy by which total evacuation cost can be minimized and the number of survivors can be maximized under a given set of geographic and resource constraints. The applicability and extensibility of the proposed model were examined by conducting a computational experiment using a large-scale realistic instance based on the city of Galveston, Texas.

Jumadi et al. [27] proposed a methodology based upon the experience of managing the crisis of Merapi 2006 and 2010. The simulation model has been developed to determine the probabilities of emerged problems while evacuation and the associated population risk. Using this model, the evaluation of the evacuation plan has been performed to find the expected problems of the plan in different scenarios. The simulation has been done considering the relation of stakeholder, volcano, and population within the environmental model. These entities have been simulated as agents with specific attributes, behavior and job.

Na and Banerjee [47] designed an *Agent-Based Discrete Event Simulation (ABDES)* modeling framework based on an embedded GIS module for developing evacuation planning in case of a no-notice natural disaster. To provide optimality to the user, the average or maximum evacuation time of all evacuees and the duration of time for each evacuee to remain in-network created by evacuation traffic under given geographic and resource limits are required to be minimized. This situation creates serious consideration for developing a realistic evacuation traffic network. So, for this purpose ABDES modeling approach has been contemplated to propose a tactical evacuation plan with different kinds of evacuees, shelters, and evacuation vehicles in a real evacuation traffic network. The proposed framework has served as a basis for a large-scale evacuation decision support system, a cybersecurity system and an emergency system in a smart city for evacuation planning.

5.4 Social-Force Model Based Evacuation Frameworks

Ha and Lykotrafitis [20] designed an agent-based system of self-moving particles to indicate the effect of complex building architecture and panic level in evacuation time during an emergency evacuation. In this study, it has been investigated that how the main exit size, size of the room door, the friction co-efficient, and desired speed affect the evacuation time. The situations under which the evacuation efficiency increases have also been discussed in this work. And, four scenarios have been considered to determine the same. It has been observed that for one room evacuation if the door size was small, then more desired speed increased the evacuation time because of congestion. For one floor with two rooms and the main exit in the hallway, the efficiency increases under certain cases because decreasing door size decreases evacuee's flow to the hallway causing less congestion at the exit. For multi-room one floor or multi-floor building, the evacuation efficiency has been affected mainly by the main exit size.

D'Orazio et al. [16] designed an agent-based model depending upon the results shown by videotapes of the real events to analyze the behavior of pedestrians in evacuation phases. The results have been depicted by a pattern of chronological arrangement of analyzed behavior of evacuees during the earthquake evacuation. Moreover, the agent-based model has been presented by incorporating i* language and determining the interaction between the environment and pedestrians. The main aim of this model was to analyze the behavior of crowd as a whole to choose the evacuation path and to determine damage distribution after the earthquake.

Balakhontceva et al. [4] developed a model to simulate agent movement on inclined decks of a ship under storm conditions. The model allowed evaluation of evacuation time during different environmental conditions and could be helpful during the design process to overcome various bottlenecks on the passage to emergency exits. The results of this study obtained have shown that the proposed method consistently finds the effects linked to the motion of passengers on the ship in storm conditions and can form a basis for creating Decision Support Systems (DSS).

Out of all the works which have been studied related to disaster management, the number of articles reviewed for each type of disaster have been listed in appendix in the form of Table 3.

Also, for the aforementioned section, for all the evacuation models reviewed, for the apropos comparison of them, the category of various reviewed models, the key methods used in development, simulation/ implementation tools used, presence of various characteristics in a model, type of evacuation, type of area/space considered in the model, no. of evacuees and limitations/future work of the same have been described as Table 6 in appendix.

6 Discussions

In this section, the major findings of the systematic literature review have been discussed. It starts by focusing on the key subareas and continued by focusing on the historical distribution of conspicuous researches related to application of multi-agent systems in disaster management. Later, the practical impacts of the study have been interpreted and the scope and validity of the present study are conferred as well. However, this review discussed various aspects, and concluded that a variety of different kinds of approaches should be combined to study evacuation in case of different evacuation situations. Moreover, psychological and physiological elements affecting individual and collective behaviors also need to be incorporated into the evacuation models for a more realistic evacuation simulation.

6.1 Key Sub-Areas of the Review

Many research papers from different journals as well as from the various other fields of study have been analyzed while writing this article to accustom the researchers' art of showing up their works, which eventually emanates this literature work.

The study has been classified into the following distinct sub-areas obtaining prominence from different research fields such as:

(i) Evacuation Modeling Approaches
(ii) Evacuation Planning Issues
(iii) Basis of Evacuation Model
(iv) Agent-based Evacuation Models

The presented literature review has acknowledged that different agent-based models that have been developed to address the challenges of different types of evacuation. In this context, first, various state-of-the-art evacuation modeling approaches in the form of *macroscopic, mesoscopic and microscopic models, and their taxonomy* have been discussed along with their relative pros and cons.

Second, *various evacuation planning issues, i.e., trav-el demand, distribution of relief resources, settlement sitting, transport mode choice and evacuation behavior*, that can be considered to plan an evacuation, in case disaster occurs have been discussed. According to most of the researchers, these planning issues actually form the basis on which evacuation models can be developed.

Third, BDI Agents, which form the basis of an evacuation model in majority of frameworks have been outlined, by elucidating *various reasons for selecting BDI architecture* as the footing of the same. Also, *various components of BDI agent which determine the behavior and psychology of an evacuee* during the evacuation process have been portrayed. Various types of *elemental agents* with disparate functionalities, which can work in any primitive multi-agent based evacuation system, i.e., *disaster control agent, unit agent, target agent, rescue agent and interacting agent* have been illustrated as well.

Finally, the classification of various multi-agent bas-ed evacuation models that can be implemented during disasters like Tsunami, earthquake, building fire, hurricane, and others, which is actually the limelight of this survey have been described in Sect. 5. These multi-agent based evacuation models have been categorized by us in the form of *Decision Support System Based Evacuation Frameworks, Evacuee Behaviour Based Evacuation Models, Geographic Information Bas-ed Evacuation Models and Social-Force Based Evacuation Frameworks*. The qualitative comparison of these disparate reviewed frameworks on the basis of various facts and characteristics present in them has been described in the form of Table 6.

For modeling and simulating all the aforementioned agent-based evacuation models, different types of simulation tools/platforms have been used. Depending upon whether the scope,structure and behavior of evacuating entities in the model to be framed, these tools/simulators can be categorized as macroscopic, mesoscopic or microscopic. Almost all the evacuation models which have been discussed in this section use either mesoscopic or microscopic simulation frameworks. For implementing, mesoscopic models, Artisoc simulator [73], MASSEgress [50], DynusT [66], Agent Analyst [69] and JAVA with NE-AT [87] have been used, as these tools attempt to gain the best of both micro- and macro- simulation by simulating both organizational structure and evacuating entities described in the model. In order to simulate various microscopic models(they are present in majority) covered in this review, NetLogo [5, 11, 21, 35, 42, 43, 48, 53, 76, 77, 77, 91], Repast (Recursive Porous Agent Simulation Kit) Simphony [54, 88] , VISSIM [7, 17], AnyLogic [27], Unity [57], CEM-PS (Configurable Emergency Management and Planning Simulator) [10], MatSim [90], FDS [63] and other simulation platforms have been used.

The comparison between most relevant simulation platforms with their significant features (with respect to literature) have been described in the form of Tables 4 and 5 present in appendix.

After reviewing disparate multi-agent based evacuation models, it has been found that these agent-based models

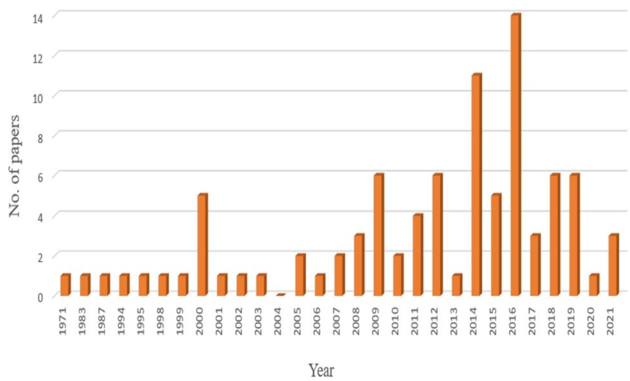

Fig. 7 Year-wise distribution of papers considered for literature review

also highlight the open research challenges in the respective field of research. To limit this survey, other issues related to evacuation planning during an evacuation have not been considered. Moreover, the review has been constrained only to the discussion of agent-based evacuation models, and other frameworks have not been taken into account for describing the evacuation process during an emergency.

6.2 Strengths of Literature Review

The significance of the presented literature review is that it gives a reasonable amount of information about various agent-based models used for evacuation purposes in an emergency along with their advantages and disadvantages in a comprehensive manner. The limelight of this study will help the researchers to know about various evacuation modeling approaches, evacuation planning strategies to deal with such situations, and models that have been implemented to overcome these no notice natural disasters. Moreover, in the article, it has been shown that how much work has been done in all the different presented models by considering the range of articles in years up to 2021.

6.3 Historical Distribution

This subsection provides the results about the growth of specific studies that have been done in the past over many years. The relevant publications have been considered after performing QA, SSS and DEO, which can answer different RQs from Sect. 1 for answering the gaps in existing approaches (RQ1) to Sect. 7 for stating the future perception of this research. The year-wise distribution of these papers has also been shown in Fig. 7, and it has been apparent that the proportion of research papers concerned with review are maximum in the year 2016.)

6.4 Analysis of Practical Impact

To analyze the efficiency of existing studies has been one of the most challenging tasks during this survey, although the authors have attempted to scrutinize their practical impact by considering the citations.

6.5 Research Validity

The authors have attempted to survey the existing literature cautiously. However, some primary studies have been remained untouched because of the devised Search Strategy since different researchers have used different synonyms related to their studies. Additionally, to avoid the biases of the study selection problem, the authors have reviewed the techniques thoroughly during DEO activity as well.

7 Conclusions and Future Work

This research work emphasizes classifying different agent-based evacuation models taking into consideration various evacuation constraints. It has been acknowledged from various research works performed in the past that many researchers have shifted towards considering different evacuation planning issues to achieve safe evacuation so that the mortality rate can be minimized. In the context of the same, this literature review highlights the survey incorporating different agent-based evacuation models employed for evacuation planning and simulation of different types of disasters. Few limitations and research gaps which can be identified after performing this review were,

- Existing literature described that all the models performed well on a smaller number of subjects. However, there are no convenient evacuation planning strategies as per the review, that can perform well even on a large data set. There is a need to check whether different convenient evacuation planning strategies can perform well even on a large data set.
- Also, the authors in various researched have not considered based on what parameters, which type of model performs better while taking into account different evacuation models.
- Not all the evacuation issues that can arise during any disaster can be covered. No single model can be defined in terms of accuracy.

Therefore, setting up some benchmarks has become the need of the hour with the proliferation of agent-based evacuation models employed for evacuation planning and simulation of different types of disasters. The future work involves addressing issues related to effect of smoke and toxic gases on evacuation process. Secondly to extend the number of subjects on which research has to be performed and to evaluate building exit(s) design for effectiveness before they are constructed. At last, it can involve and incorporate an improved version of the aforementioned strategies for disaster management. Henceforth, in future, we wish to extend this work ny devising some improvised multi-agent based evacuation model which can address one or more of the research gaps which have been pinpointed in this review.

Appendix

See Tables 3, 4, 5 and 6.

Table 3 No. of articles reviewed for each type of disaster

Type of disaster	Building fire	Hurricane	Tsunami	Earthquake	Flood	Miscellaneous disasters
No. of articles reviewed	8	6	5	3	2	11

Table 4 Various simulation tools referred in this review with their significant features

Simulation tool	Mesoscopic/microscopic	Significant features
NetLogo	Microscopic	Is multi-agent programmable modeling environment Well suited for modeling complex systems developing over time Provides open simulations to play with them Is an Open Source Framework Is a Cross platform tool Large vocabulary of built-in language primitives Equipped with powerful APIs Equipped with display and visualization module Equipped with BehaviorSpace
Repast simphony	Microscopic	Used extensively for the social simulation, manufacturing, supply chain and biomedical modeling applications Supports development of extremely flexible models of interacting agents for use on workstations and computing clusters Equipped with powerful APIs Richly interactive modeling tool Written in JAVA Is an Open Source Framework Is a Cross platform tool Follows a modular approach Includes automated results analysis connections to a variety of spreadsheet, visualization, data mining, and statistical analysis tools
VISSIM	Microscopic/mesoscopic	A behavior-based micro-simulation system developed by Planung Transport Verkehr (PTV) Utilizes a discrete, stochastic psycho-physical driver behavior model Capable to effectively model traffic operations under various conditions Efficiently model origin/destination based traffic demand Is not free to use (is a proprietary software)
Unity	Microscopic	Unique hybrid of 3D modelling and level design tools Used to prototype structures, complex terrain features, vehicles and weapons Is an Open Source Framework Is a Cross-platform tool Has a powerful visual interface for designing video games and performing simulations of Physics oriented events Able to export models to WebGL form

Table 5 Various simulation tools referred in this review with their significant features—in continuation to table 4

Simulation tool	Mesoscopic/ microscopic	Significant features
MatSim	Microscopic	Used to implement large scale agent-based mobility simulations Equipped with powerful APIs Written in JAVA Is an Open Source Framework Multiple iterations are made until agent-based user equilibrium (UE) is reached Offers a microscopic engine which reduces complexity of computation Enabled with large scenario analysis (millions of agents) Can be used to simulate both private and public traffic Follows a modular approach
MASSEgress	Mesoscopic	Can potentially be used for many practical mesoscopic modeling applications Facilitate egress analysis for building designs(multi-storeyed buildings) Can model building occupants as individual agents equipped with sensors, brains and actuators for egress analysis Can use this freely for non-commercial purpose at our own risk Developed for research purposes only
DynusT	Mesoscopic	Is the most widely used simulation-based Dynamic Traffic Assignment (DTA) model due to its superior traffic simulation realism and computational efficiency Is applies a micro-like features to mesoscopic vehicular traffic simulation model Capable of simulating a wide range of operational planning scenarios Available with breakthrough in dynamic traffic assignment with individual Value-of-Time Has improved DTA simulator with extended horizon up to 9999 minutes Has improved assignment speed with multi-threaded assignments Has new link tool for removing shape points Is a proprietary software Equipped with a strong set of APIs Equipped with 2D/3D Google Earth mapping tools

Table 6 Comparison of related work on different Agent-based Evacuation Models

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
1.	Silva and Eglese [10]	Microscopic	Spatial Decision Support System (SDSS), a traffic simulator was integrated with GIS	CEMPS (Configurable Emergency Management and Planning Simulator)	Not described	Nuclear Disaster Evacuation	Large Area	Not described	To provide dynamic simulation modeling, enhancement in GIS still needed
2.	Chen et al. [7]	Microscopic	Discrete, stochastic psycho-physical driver behavior-based model	VISSIM V3.70	Varying congestion levels for different simulation runs	Hurricane Evacuation	Roads	92,596	Urban scenarios with congested traffic and vulnerable communities has not been considered
3.	Pan et al. [50]	Mesoscopic	Prototyped MASS (Multi-Agent Simulation System), SafeEgress and K-Means Clustering	MASSEgress	Crowd density, peers' imposed mental stress, environmental constraints	Building Floor Evacuation	Office Building	Not described	To improve the tool to perform statistical analysis of evacuation time and flow patterns, design parameters
4.	Uno and Kashiyama [73]	Mesoscopic	MAS based Disaster Evacuation model integrated with GIS, Shortest Path Algorithm	Artisoc Simulator	Refuge cognitive Ratio, walking Speed, time to start Evacuation	Flood Evacuation	An Urban area in a city in Japan	630	Modification and verification of model to be performed yet
5.	Zhang and Ukkusuri [88]	Microscopic	Agent-based hurricane evacuation model, Dijkstra's Shortest Path Algorithm	Repast Simphony	Tolerance limits assigned to normal and greedy Agents	Hurricane Evacuation	An urban area comprising several households	50-1000	To examine accident situations and passing over behavior of agents
6.	Shi et al. [63]	Microscopic	AIEva, based on Agent Evacuation Dynamic Mathematical Model	FDS (Fire Dynamics Simulator)	Health and mobility of evacuee, environmental driving factors like exits driving factor, dangers, eject factors, crowd attraction factors	Building Fire Evacuation	Public Building	Not described	To consider more complicated psychological aspects of escape movement for a more flexible model
7.	Ren et al. [54]	Microscopic	Agent-based modeling and Simulation (ABMS)	Repast Simphony	panicked and nervous individuals, obstacles created by fallen or injured people	Building Fire Evacuation	Building Basement	506	Addressing system issues, computational cost, memory efficiency and reuse of a map

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
8.	Edara et al. [17]	Microscopic	Hurricane Evacuation Network Model and a muti-phase traffic control plan	VISSIM	Combination of storm intensity and hotel occupancy	Hurricane Evacuation	Road Network of 2000 miles connecting 10 cities	Approx. 10,000	To choose parallel processing of road network scenarios
9.	Madireddy et al. [35]	Microscopic	Agent-Based Simulation (ABS) Evacuation Model	Net Logo	Traffic blocking and unblocking Rules	Traffic Evacuation	Sioux Falls Road Network	2000	Combine throttling and contraflow, Use Optimization via Simulation (OvS), to find metric to identify ideal throttling links
10.	Songchitru-ksa et al. [66]	Mesoscopic	Dynamic Traffic Assignment Model	DynusT	Network and facility wide performance measures	Hurricane Evacuation	Houston Galveston Region (A City)	Not described	Factors like vehicle breakdown problem and incidents like lane blocking have been not taken into account
11.	Ha and Lykotrafitis [20]	Microscopic	ABM (Agent-Based Modeling) based on Molecular Dynamics	Not described	Panic factor, Congestion Effect	Emergency Building Evacuation	Multi-floor Building	200	Not described
12.	Manley and Kim [38]	Microscopic	Agent-based Public Decision Support System (Exitus)	OOP (Object Oriented Paradigm)	Individuals with disabilities	Emergency Evacuation	Multi-floor Building	71	To include empirical studies, examining time and equipment needed to affect assisted evacuations, theoretical studies adding external and social force in the model development

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
13.	D'Orazio et al. [16]	Microscopic	Agent-based Behavioral Model for Earthquake Pedestrian's Evacuation	Open Source Image Analysis Software Tracker and i* Graphical Modeling Language	Environment factors like position of safe areas, relative seismic vulnerability, Pedestrian factors like average speed in motion, radius and mass of a pedestrian	Earthquake Pedestrians Evacuation	Outdoor public space (streets, squares...) or indoor wide spaces connected directly to outdoors ones (wide halls, private gardens)	27	Not described
14.	Tan et al. [69]	Mesoscopic	Agent-Based Building Evacuation Model, Shortest Path Algorithm	Agent Analyst	Obstacles(stationary and moving)	Building Fire	Campus Building (Second floor)	680	Considering evacuees reaction to smoke, effect of cell dimension on simulation
15.	Na and Banerjee [46]	Microscopic	ABDES (Agent-Based Discrete Event Simulation) model	ARENA 14.0 and ArcMap 1.0 using Python	Three types of shelters, i.e., extensive, restrictive and other large shelters	Large Floor Disaster Network	Galveston City, road network	Study 1: 6835 Study 2: 8538 Study 3: 9465	Design various scenarios with non-functional shelters and inaccessible roads
16.	Wagner and Aggarwal [76]	Microscopic	Agent-based Decision Support System, Ray-casting and Quadratic Bezier curves, Fire Dynamics and Person Movement Algorithm	Net Logo	Smoke rate, maximum accumulated smoke limit	Building Fire	Concert Venue (Stadium & Auditorium)	(4055 + 420)	Physical model of fire and complex model of personal decision-making capability can be incorporated
17.	Liu et al. [33]	Microscopic	ABM (Agent-based Model)	LS-DYNA and NetLogo	Social behavior, building damage, heterogeneous population	Single Multi-floor Building	Earthquake Evacuation	259–450	The presented model can be extended for large community wide models.
18.	Wolshon et al. [81]	Microscopic	TRANSIMS (Transportation Analysis and Simulation System)	Vehicular Micro-simulator and GIS (Geographical Information System)	Travel Characteristics (source, destination of evacuee)	Traffic Evacuation during hurricane	Gulf Coast region of the United States (multiple cities)	2,834,893	More details of traffic network performance can be explored

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/ macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/ space considered	No. of evacuees	Limitations/future work directions
19.	Wang et al. [77]	Microscopic	Agent-Based near-field multi-modal Tsunami Evacuation Model	NetLogo	Factors interfering with evacuation capacity, i.e., single female headed households, being elderly, disability, racial/ethnic minority	Tsunami Evacuation	City of Seaside, Oregon	2500	The transportation network partial damage due to bridge vulnerability can be studied, the bottleneck effects, transportation behavioral models like green shields model incorporation can be checked, the realistic interaction rules among agents can be included
20.	Ahn et al. [3]	Microscopic	ABM (Agent-based Model)	Testbed	Spatial recognition of occupants, variation of exit width	Building Fire Evacuation	Shopping Mall	2500	Factors like fire smoke, the effect of toxic gases and transportation vulnerability can be taken into consideration
21.	Balakhont-ceva et al. [4]	Microscopic	Multi-disciplinary Multi-agent Simulation Model	CLAVIRE	Crew proficiency, ship safety, individual characteristics of passengers' behaviour	Storm Evacuation for Damaged ship	Ship Cruise	8	The developed system is too slow for accelerated online evacuation simulations
22.	Jumadi et al. [27]	Microscopic	ABM (Agent-based Model and GIS)	Anylogic	Time onset for volcanic eruption	Volcanic Evacuation	City of Merapi, Indonesia	Approx. 50,000	Population behavior variability, to investigate volcanic activities temporal characteristics, consider all actors participating in disaster management

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
23.	Zhu et al. [90]	Macroscopic	ABS (Agent-based Simulation) model, Monte-Carlo Markov Chain (MCMC) sampling technique	MATSim and Open Street Map	Evacuation preparedness, choices and destinations, evacuees' income, auto-ownership and education	Hurricane Evacuation	Seven Counties of north New Jersey	2,184,802	Efficient techniques to estimate background traffic can be added, Data requirement to find extra destination choices can be added, Activity-based model to multiple day scenarios can be expanded, Intensity of hurricane parameter into the demand model can be incorporated
24.	Kasereka et al. [29]	Microscopic	Intelligent Agent-based Navigation Model, Dijkstra's Shortest Path Algorithm	GAMA platform	Presence of fire, smoke and their propagation, and obstacles	Building Fire Evacuation	Super Market	10-300	The real-life situations can be considered by adding fuzzy logic to the model
25.	Poulos et al. [53]	Microscopic	Agent-based Building Evacuation Model	NetLogo	Agent Speed, Diameter and Obstacles	Tsunami Evacuation	K-12 School Building	1500	The effectiveness of different exits of a building before their construction can be checked, the effect of social behavior on evacuation can be checked, large-scale evacuation at block and city scale can be addressed

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
26.	Yuksel [87]	Mesoscopic	Agent-Based Evacuation Simulation Model with NEAT	JAVA, Eclipse IDE, MongoDB, OpenGL API and NEAT (NeuroEvolution of Augmenting Topologies) method	Visible targets, obstacles and efficient locomotion	Emergency Crowd Evacuation	Public indoor environment	200–500	Not described
27.	Mostafizi et al. [43]	Microscopic	Agent-based Tsunami Evacuation Model	NetLogo	Milling Time, transportation System Damages,travel speed variation	Tsunami Evacuation	City of Sea Side, Oregon	Not described	Not described
28.	Delcea and Cotfas [11]	Microscopic	Agent-Based Model	NetLogo	Presence of multiple exits, congestion, exit width, obstacles, different classroom layout	Fire Evacuation	Classroom in a school building	30	Research performed upon a limited number of pupils and can hence be extended in order to be used for real-life simulations
29.	Sahin et al. [57]	Microscopic	Multi- agent based Crowd Evacuation Model using Fuzzy Logic	Unity	Healing/clogging Behavior, exit width, leadership assignment	Crowd Evacuation	Building	60–160	To make simulation planning more realistic by designing a partially observable model -The social network among evacuees to make dynamic groups while evacuation can be created
30.	Na and Banerjee [47]	Microscopic	Agent-based Discrete Event Simulation Model	Simio 10.11, Agent library and ArcMap 1.0	Three types of shelters, i.e., extensive, restrictive and other shelters	Large Scale Earthquake Evacuation	City of San Francisco	2,00,000–2,40,000	Relief logistics problem has not taken into consideration

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
31.	Nakanishi et al. [48]	Microscopic	Agent-based Model for Flood Evacuation Behavior of older people	NetLogo	Elderly old people with declining health and increased chronic diseases, limitations in vision, hearing and mobility restrictions and limited access to healthcare resources	Flood Evacuation	Rural Town of Manno, Japan	4097	The utility of the model on an identical road network on an another open-source ABM platform such as MATSim can be tested
32.	Mostafizi et al. [43]	Microscopic	ABTEM (Agent-based Tsunami Evacuation Modeling)	NetLogo	Socio-demographic characteristics such as choice of evacuation mode, milling time, walking speed	Tsunami Evacuation	City of Seaside, Oregon	6700	To model coalescing behavior, car-abandoning and interactions in a realistic environment
33.	Wang and Jia [78]	Microscopic	Multi-modal tsunami evacuation model	NetLogo	Seismic damage to road links, fragility curves of roads/bridges, volume ratio of pedestrians	Tsunami Evacuation after earthquake	Seaside, Oregon	5000–15,000	To use probabilistic sensitivity analysis, that can provide information regarding risk assessment and risk mitigation purposes
34.	Zia et al. [91]	Microscopic	Agent based Model based on discrete time and space simulation	NetLogo	unevenness between exits, obstacles, panic factor	Crowd Evacuation	Residential Buildings, Factories, Offices	1000	Human behavior and environmental dynamics are not explicitly verified
35.	Hassanpour et al. [21]	Microscopic	Dynamic Agent-based Simulation model	NetLogo	Blurred perception, panic factor	Emergency Evacuation	Subway Platform	2500	To calibrate utility function using real data, use stochastic approach to make model more realistic, coupling model with constructional tools

Table 6 (continued)

S. No.	Author name (year)	(Microscopic/macroscopic/mesoscopic) model	Key methods used	Simulation platform/tool used	Presence of different characteristics	Type of evacuation	Type of area/space considered	No. of evacuees	Limitations/future work directions
36.	Barnes et al. [5]	Microscopic	ABM (Agent based Modeling) framework	NetLogo	Population distribution , appropriate walking speeds, distribution of group sizes, and walking speed ratio	Natural Hazard Evacuation	Shopping Street and City Centre	1000–10,000	To focus on realistic representation of human behavior within the model environment

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