Agent-Based Modeling and Simulation on Emergency Evacuation

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Abstract. Crowd stampedes and evacuation induced by panic caused by emergences often lead to fatalities as people are crushed, injured, trampled or even dead. Such phenomena may be triggered in life-threatening situations such as fires, explosions in crowded buildings. Emergency evacuation simulation has recently attracted the interest of a rapidly increasing number of scientists. This paper presents an Agent-Based Modeling and Simulation using Repast software to construct crowd evacuations for emergency response from an area under a fire. Various types of agents and different attributes of agents are designed in contrast to traditional modeling. The attributes that govern the characteristics of the people are studied and tested by iterative simulations. Simulations are also conducted to demonstrate the effect of various parameters of agents. Some interesting results were observed such as "faster is slower" and the ignorance of available exits. At last, simulation results suggest practical ways of minimizing the harmful consequences of such events and the existence of an optimal escape strategy.

Keywords: Agent-Based Modeling and Simulation, Evacuation, Escape Panic, Repast Simphony.

1 Introduction

Emergency evacuation is the urgent movement of people from a dangerous place due to the threat or occurrence of a disastrous event [1]. Examples are the evacuation of a building due to fire and the evacuation of a district because of a flood. Evacuations may be carried out before, during or after natural disasters. Emergency evacuation can be a life or death situation, whether initiated by a natural disaster or a terrorist attack.

Emergency evacuation will cause lots of casualties, as it often leads to the death of people who are either crushed or trampled down by others. And unfortunately, the frequency of such disasters is increasing. The ability to evacuate hundreds of thousands of people in a very short amount of time can save lives. But evacuation drills may present significant both practical and financial challenges to researchers. To conquer these challenges, several types of crowd simulation systems have been

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developed, such as flow dynamics based simulations; cellular automata based simulations and agent-based simulations. Several essential types of emergence evacuation is widely studied especially after the famous “9.11” attack in USA., for example, evacuation from buildings [2], evacuation from ship [3], evacuation from station [4], evacuation in dark [5], evacuation for individuals with disabilities [6], evacuation caused by fire [7], crowd simulation of military [8] etc. The practical ways of minimizing the harmful consequences and the existence of an optimal escape strategy can be concluded via simulation results.

Most computer models for emergency evacuation are developed by social psychologists and others. It is often stated that panicking people are obsessed by short-term personal interests or self-serving psychology uncontrolled by social and cultural constraints. As a result, lots of options like side exits are mostly ignored. These irrational phenomena are possibly a result of the intensive fear. Furthermore, individual panic will transmit to other neighboring him which will cause mass panic and often leads to bad overall results like dangerous overcrowding and slower escape. These psychology factors must be taken into account in an evacuation model which is supposed to be designed precisely.

Most computer based simulation evacuation models are based on flow dynamics, cellular automata, activity, and multi-agent design. Flow based models are easy to construct while they lack social interaction between evacuees, human behavior in emergency conditions and hazards representation [9]. Cellular automata [10, 11] are a special kind of Multi-Agent System [12, 13] with very primitive agents similar to finite state machines (FSM), arranged on a rigid grid, and interacting with one another by very simple rules. MAS and CA are used today to explain complicated and complex systems, for example in economics, biology, history and conflict analysis, politics and political science, Sociology and social science [14].

MAS are particularly suitable for modeling human behavior, as human characteristics can be objectively mapped to agent behavior. So, the agent-based simulation for evacuation has become a key research field [15, 16, 17, 18], and lots valuable results are reached [19, 20]. Most of the research has been concentrated on two distinct problems, evacuation of buildings and evacuation of large areas, like entire cities or coastal plains. Some of the earliest research on building evacuation was done by Chamlet, Francis and Saunders [21]. Their paper describes three models they developed to analyze clearing time, bottleneck locations, and general performance of a building in the event of an evacuation. The most important of these models is the dynamic model that represents the evacuation of a building as it evolves over time. With these models they were able to make general estimates of clearing time for a specific building. This paper has played an important role in subsequent research as people have used this work to facilitate research of their own [22, 23, 24]. Another important and famous paper about evacuation simulation is written by Dirk Helbing et al. [25] which get lots meaningful results.

The scenario considered in this paper is the management of crowd evacuation under emergence of a fire accident using Repast whose purpose was to explore how to evacuate from a building on fire more effectively and whether the building convenient for evacuation during emergency evacuations. The character of the model, including character of the agent (people) and environment (both fire and the building), is discussed. In this paper, various types of agents and different attributes are designed and the interactions of them are concerned in contrast to traditional models which consider the total populations are consisted of identical individuals and omit their interactions. Lots of interesting and valuable results was gained via doing experiments many times.

Briefly then, the outline of this paper is as follows. In Sec. 2 we discuses the benefits of agent-based modeling and simulation (ABMS) and introduce the ABMS software Repast, Sec. 3 discuss the detail and techniques of emergency evacuation modeling and simulation using Repast, Sec 4 discuses the experiments and its results, Sec 5 gives the conclusion and future work to do at last.

2 ABMS and Repast

Currently, there is no reliable and valid way to wholly delineate and model the complex systems, including the complex adaptive systems (CAS). Our current work hones in on the emergency evacuation management, but what we are learning about system modeling has implications for modeling any complex system that involves many human interactions and where the actors work with some degree of autonomy.

Within lots of fields such as economics, social science, psychology, retail, marketing, artificial intelligence, and computer science, a wide variety of approaches are used which can be classified into three main categories: analytical approaches, heuristic approaches, and simulation [29]. Simulation introduces the possibility of a new way of thinking about social and economic processes, based on ideas about the emergence of complex behavior from relatively simple activities [30]. Among these three approaches, simulation is competent for study the emergency evacuation management.

Modeling and simulation technique is helpful for clarification, implementation, proving, and validation of a theory. The accuracy and effectiveness of a simulation model depends upon the right level of abstraction and precision of the accurate model. There are several widely used paradigms in simulation modeling. The most popular ones include discrete event simulation (DES), system dynamics simulation (SDS), and agent based simulation (ABS) [31] which focus on and dedicated to different fields of simulation. For example, SDS deals mostly with continuous processes whereas DES and ABS operate mostly in discrete time steps, ABS deals mostly with the system that composed of autonomy individuals.

The choice of the most suitable approach always depends on the characteristics of the system to be investigated. Generally speaking, ABS is more suit for modeling the complex system. They are complex because they are made up of a large number of multiple mutually interacting and interwoven parts. Examples include: neural and social networks, nervous and immune systems, ancient and modern cultures, economics, ecosystems, sociology and society science, politics and political science.

Agent-Based Modeling and Simulation (ABMS) is a powerful simulation modeling technique, and there are a number of applications in the last few years, including applications to real-world business problems. In ABMS, a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually apperceives the states of him and environment, and interacts with other agents, then makes decisions on the basis of a set of given rules. Advanced agents can even change their action rules as they gained experience. Even a simple ABMS can exhibit complex behaviors and provide valuable information about the dynamics of the real-world system that it emulates. Sophisticated ABMS sometimes incorporates neural networks, evolutionary algorithms, or other learning techniques to allow realistic learning and adaptation. ABMS is still a relatively new simulation technology, which only became popular in the early 1990s, although computer simulation has been widely used since the 1960s.

ABMS can be used to study how micro-level processes affect macro level outcomes. Macro behavior is not explicitly modeled; it emerges from the micro-decisions of individual agents [29]. Based on some simple types of rules, ABMS can be used to study how system-level and individual-level patterns emerge from rules at the individual level. Due to the characteristics of the agents, ABMS approach appears to be more suitable for modeling human-based systems, especially for Complex Adaptive Systems (CAS) which is made up of agents that interact and reproduce while adapting to a changing environment. There are many examples of systems comprised of interacting individuals: (1) Economic markets with producers, distributors, and consumers (2) Social systems with people, groups, factions, and countries (3) Ecosystems with species, individuals, hives, and flocks.

The benefits of ABMS over other modeling techniques are: it's flexible, captures emergent phenomena, and provides a natural description of a system [26]. So, ABMS is ideally suited to provide valuable insights into the mechanisms of and preconditions for panic and jamming.

ABMS is a field that in the past 10 years has seen not only rapid growth in applications, but also development of several platforms, toolkits and frameworks for assisting multi-agent model designers thanking to lots of public research and development investments. The celebrated open-source software environments include Swarm, Repast (Recursive Porous Agent Simulation Toolkit), MASON (Multi-Agent Simulator of Neighborhoods), and NetLogo. By using these toolkits or platforms (except for NetLogo), Multi-agent model developers can design their models using Java, C++, or other similar languages [33].

These toolkits and frameworks all provide tools for designing agents as well as provide tools for developing an environment in which the agents interact. However, none of these toolkits and frameworks has provided an infrastructure that supports highly modular sets of behaviors and relationships. By factoring agents, relationships, and behaviors into separate components, the Repast intends to provide tools to create more modular and expressive models [33].

The Repast has been used extensively in social simulation applications. The latest version of Repast is Repast Simphony. Models can created with the visual designer (e.g., visual point-and-click tools are provided for designing agent model, specifying agent behavior, executing model, and examining results), or written in Java or any language that runs on the Java virtual machine. For example, users can design the logical structure, spatial structure (e.g., geographic maps and networks) and behaviors of their agent models by point-and-click. The simulation is visual and results are stored. In addition, Repast includes automated results analysis connections to a variety of spreadsheet, visualization, data mining, and statistical analysis tools [26].

3 Crowd Simulation Model and Simulation

One common deficiency of traditional models is that the differences in characteristics and behaviors of individual evacuees are not taken into account even though such differences are quite obvious, e.g., the people are regarded as equally the same individuals and evacuation crowds as flows in the flow-based model and Cellular Automata simulation methods. One main reason for this deficiency is that such differences are extremely difficult to convert into physical models.

It is useful to think of evacuation behavior during emergency egress having three distinct analytical dimensions: the environment and its configuration of the evacuation; the managerial policies, procedures, and controls deployed at evacuation; and the social psychological and social organizational characteristics impacting the response of persons and collectivities that participate in the evacuation. Much more studies of the first two are found than of the third. So, the third dimensions are emphasized in the agent-based models designed in this paper, and the following 5 hypothesis or facts are considered in the fire emergency evacuation [20]:

- In situations of emergency evacuation, individuals are getting panic and nervous, so as to tend to develop blind and irrational actions.
- People try to move as fast as they could, which considerably faster than normal.
- People are getting eyes hurt and hard to breathe as the smoke is toxic. Situations become worse when the smoke getting thicker, in this case, people may could not see the floor and find the exit available.
- Individuals start pushing as well as are pushed by others, so there are pressures in evacuation crowds by physical interactions.
- Evacuation crowds are slowed down by fallen or injured (even dead) people turning into "obstacles".

In our agent-based models, several types of people are explored (e.g., men, women, children, security guards and evacuation leaders if necessary), as well as the various attributes (shown in Table 1) of agents are taken into account.

The scenario used in this paper is the real-world experiment conducted by Sugiman [27], as shown in Fig. 1. We adopt the place structure of Fig.1 which is a basement that is roughly four meters wide by nine meters long with three exits. The attributes of people and the place configuration can be easily designed in Repast in which person is regarded as agent and place as “network” and “Grid”.

In addition, the environmental characteristics that this model considered are as follows [28]:

- The total number of people in the area
- The number of exits
- The number of policeman in the area
- The number of security guard in the area
- The intensity of the fire
- The velocity of the spread of the fire
- The toxicity of the fire
- The distribution of policeman and
- The distribution of security guard

Table 1. The attributes of agents that considered in the model

Attributes	Type	Explanation
age	int	[18, 55]
sex	int	0: mail; 1: female
knowledge of the area	float	[0, 1]
leadership	int	1: leader; 0: member
independence	int	0: follow leader from the same group 1: not follow leader
injury scale	float	≥0.6 : can't move; 1: dead
positions	(x, y)	
fatigue or physical exertion	float	≥1 : can't move; fatigue will slow down the velocity
panic scale	float	panic will slow down the velocity
initial velocity	float	depends on sex and age
max velocity	float	depends on sex and age
nervousness	float	influences fluctuation strengths, desired speeds and so on

Environmental characteristics above have a significant effect on the behavior of individuals and the result of the evacuation. So, it is necessary to incorporate them for the inclusion of individuals in an evacuation simulation.

Leaders and evacuees use different rules to find the exits available. Leaders have the higher Knowledge of the area than the evacuees so they can find the exits faster. The evacuees follow the direction of the leader who belongs to the same group. There are directed lines connecting evacuees and their leaders in the Repast model, so as to make evacuees know their leaders' direction.

Except for the graphical agent editor which is aim mainly at the primary users, Repast Simphony allows users to design their multi-agent models by program languages to devise more sophisticated models. Obviously, the first choice is Java by which users can design behaviors, properties, tasks, and display styles of agents as well as the environment, parameters and configurations of the model. Lots of build-in Java classes are available too, which can be used to assist model designing. Another frequently used language supported by Repast Simphony is Groovy which is a dynamically typed programming language very well integrated with Java [34]. The graphical agent editor generates Groovy agent classes automatically after every change on the agent design, making the use of Groovy completely optional.

We wrote several Java classes to design our model, which are four agent classes: "Child" class, "Man" class, "Woman" class and "People" class, one display style class: "AgentStyle2D" class, and one context class: "MyContextCreator" class, as shown in Fig.1. The "People" class is the base class of "Child", "Man", "Woman" classes which defined the common properties and behaviors. The "MyContextCreator" class constructs the main context and returns it to the Repast run environment. In detail, we add a Grid projection to the context to model the world using a discrete Cartesian grid. Next, we add the agents (i.e., the Child, Man, and Woman) to the context.

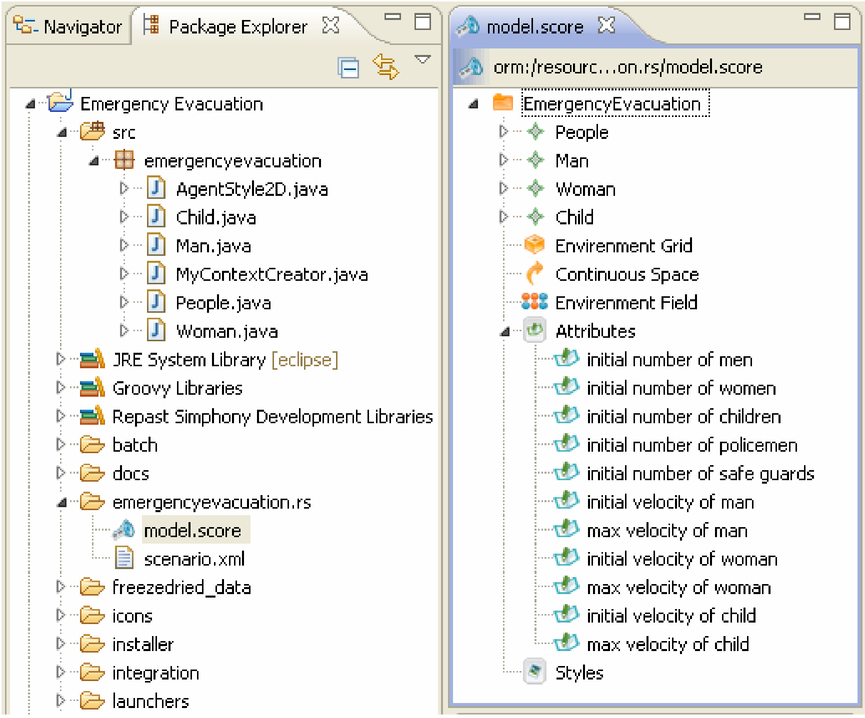

Fig. 1. The model designed by Repast Simphony

The model properties are designed in the score file, such as the initial number of agents and other model parameters as shown in Fig.1. With deferent attributes set, many different simulations can be run and various results are obtained.

4 Experimentation and Results

With different parameters (Attributes in Fig.1), such as, people distribution, the total population, the attributes of people, environmental characteristics, the proportion of evacuee and leader, the number of policeman, the number of security guard and the number of exits as well as their distribution, this experiment was run several times.

Fig. 2, Fig. 3 and Fig. 4 as follows are parts of our simulation results which demonstrate the effect of population, number of guards and leaders and the initial velocity. The base model is setup with 500 people, 3 security guards, 3 leaders, 3 exits, medium fire intensity and the leaders have the full knowledge of the area which means the leaders know where the nearest exit is and the shortest route to get there.

As the population gets bigger, the evacuation time increases rapidly meanwhile the number of casualties increase slowly as shown in Fig. 2. A reason for this is that the increased number of casualties slow down the others' movement, and bigger population may cause bigger panic scale which will make them can't response rapidly.

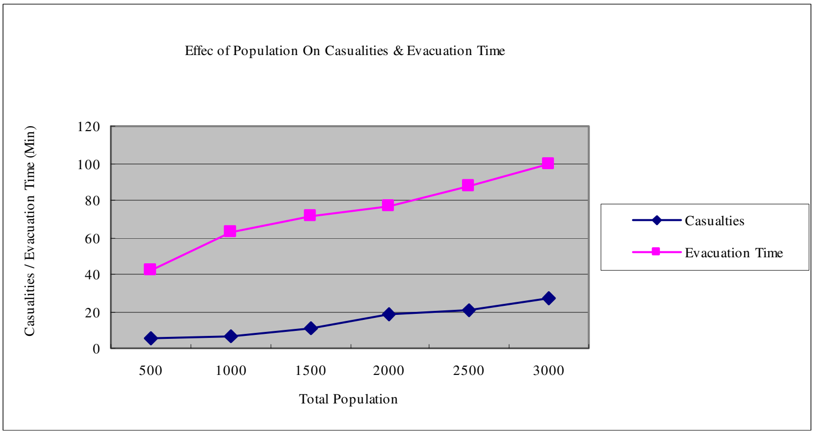

Fig. 2. Effect of Population

Fig. 3. Effect of Number of Guards & Leaders

The number of security guards and number of exits don't affect the number of casualties remarkable, i.e., the number of security guards and exit have no major relation to the number of casualties as shown in Fig. 3. Surprisingly, Fig.2 also indicates that leaders play a more important role than the security guards which perhaps means the leaders are more trustful or the leaders have a whole knowledge of the area.

The increase of the number of exits can not reduce the evacuation time significantly partly because alternative exits are often overlooked or not efficiently used which indicates that people don't know all the exits available or the configuration of the environment, or perhaps they follow others' direction as they are too nervous to make rational decision, or perhaps they cannot move where they want to as there are much pressure in crowd. Any way, it is helpful and suggested that finding out as many safe exits available as one can at prime tense after entering buildings. Similarly, the increase of the number of exits reduce the number of casualties quite slowly which perhaps indicates the number of casualties is mainly effect by the panic scale and the population scale.

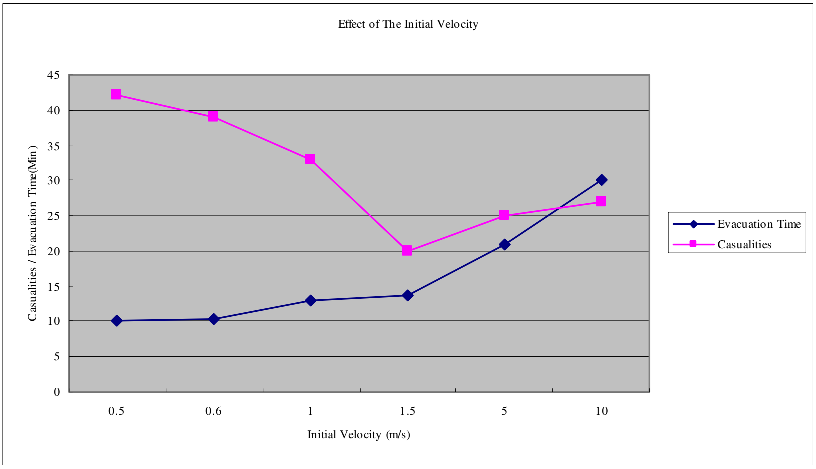

Fig. 4. Effect of The Initial Velocity

The interesting phenomenon "faster is slower" is visualized as shown in Fig.4. As everyone of the crowd wants and tries to move fast, the evacuation time is not always reduced after the velocity exceeded a certain value, and the casualties increase rapidly. This perhaps because the physical interactions in the jammed crowd add up and cause dangerous pressures and the faster velocity cause bigger pressure as well as bigger panic scale. So, as casualties' numbers increasing, evacuation crowds are slowed down by fallen or injured (even dead) people turning into "obstacles".

5 Conclusion and Future Work

Emergency evacuation will cause lots of casualties, as it often leads to the death of people who are either crushed or trampled down by others. And unfortunately, the frequency of such disasters is increasing. But evacuation drills may present significant both practical and financial challenges to researchers, so emergency evacuation simulation has recently attracted the interest of a rapidly increasing number of scientists.

ABMS can easily define the attributes and behaviors of the individuals in contrast to conditional simulation methods. This paper presents an ABMS method using Repast Simphony toolkits to construct crowd evacuations model for emergency response from an area under a fire accident which is paid close attention to and has been of interest to many researchers such as psychologists, computer scientists, safety engineers, risk managers, and architects. Several Java classes are written to specify properties and behaviors of the agent as well as the environment of the evacuation. Various types of agents (i.e., man, woman and child) and different attributes (such as age, velocity, panic scale, etc.) of agents are designed in contrast to traditional modeling. The attributes that govern the characteristics of the people are studied and tested by iterative simulations. Simulations are also conducted to demonstrate the effect of various parameters of agents, and some interesting results were observed.

Our future work involves addressing system issues such computational cost and memory efficiency because the more accurate model with tremendous number agents maybe is a system challenge. The second one is the reuse of the map, i.e., the model can use different scenarios, such as theater, hall, and supermarket. The combination of GIS which is supported by Repast maybe is an ideal choice. At last, we will validate the models we designed.

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