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**Investigation of agent-based modelling on
the simulation of crowd evacuation**

by

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requirements for the degree of M.Sc.
Applied Computing**

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DECLARATION

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Abstract

Nowadays, the crowd gathers more and more frequently in these places like shopping centre, subway or large-scale gymnasium. Once a fire occurs in these building, the evacuation of a great number of people should be a problem. Therefore, how to evacuate the crowd quickly and effectively became an essential research issue. The rise of crowd modelling techniques is a good impetus to the development of this issue. However, it has highly demands in the terms of the authenticity and credibility of the behaviour. To solve this problem, the ordinary method is to simulate the basic relationship of the crowd as much as possible. In this paper, an agent-based modelling which is based on the psychology and behaviour of person in evacuation will be built. Smoking diffusion will also be simulated in the fire situation as an important factor. This paper uses the A-Star algorithm and the algorithm of FLOCKING for the crowd evacuation simulation in the agent-based modelling. In this model, it not only describes the basic relationship as groups of the crowd, but also adds the manager agent (coordinating agent) group which is also based on the performance of different individuals in the group during the evacuation. By using these algorithms, the new modelling avoids the disadvantage of the simulation only for the individual of the group in the past models and adds the interactive decision-making and behaviours between the manager agents.

Netlogo simulation software will be used to complete the modelling realize part. It made the situations which is independent escaping without manager agents, coordinating escaping with manager agents and when the export was limited with fire smoking diffusion. The simulation results show the group relationship in the crowd and find that the manager agents on the group can influence the behaviour of other people in the evacuation process, thus improving the efficiency of evacuation.

Key words: NETLOGO, fire evacuation, agent-based modelling, A-Star, FLOCKING.

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1 Introduction

1.1 Research background

In recent years, with the rapid development of the social economy and the rapid development of urban construction, various high-rise buildings have appeared. Supermalls and shopping centers and a series of crowded places bring a lot of convenience to people's life. However they take great potential threat to the citizen at the same time, if only some accidents occurred in such places, especially the fire accident, this will cause serious injuries and great property loss. In June 2016, for example, At least 80 people are believed to have died after a huge fire engulfed a west London tower block. [1], how to make the panic crowd evacuation in a relatively short period is a severe issue, the behavior of people in the crowd also becomes the key to the research of the crowd evacuation.

Crowd Evacuation has been praised by the attention of the society as it related deeply to the life. In the past years, experts, scholars who research on evacuation worked hard but Inefficient. While in recent years, as the global population increasing and urbanization accelerating, the crowd evacuation problems become an urgent and essential subject about life. Scientific and reasonable evacuation algorithm and the preplan with the rehearsal can be successful save people's life as well as greatly reduce casualties in a fire or the other disaster. From then on, research on evacuation has begun to flourish.

1.2 Research Emphasis and Difficulties

The study on the evacuation of people in emergency situations such as fire in recent years indicates that when the emergency occurred, the result of the evacuation of a great deal of citizens was not very good, so it caused serious hurt and property damage for the individual as well as triggered a series of related losses for the whole society. What can be done to be able to avoid the risk in the fire situation or what measures could be taken as effective as the imagination? Actually, the most common method is to make reasonable scientific preplan for the specific environment and resources firstly, then doing the evacuation drill according to the plan and the last step is to feedback. The feedback will be revised and further used to perfect the preplan. But in real life, this kind of plan could not be realized. Because that it is difficult to use the field exercises and other means to simulate the actual process of crowd evacuation. First of all, there are certain dangers in the field exercises, which can easily lead to casualties if someone makes mistakes. Secondly, the field exercises need lots of people to participate in so the cost of the exercise is high. Third, it is a random and sudden accident as well as a complex dynamic process, field exercises cannot fully reflect the crowd evacuation as the real one, it has great difference between the real accident. However, by setting up the scene model on the computer, the crowd evacuation can be built with crowd

modeling technology .it has the advantages of the low cost, high efficiency and high scientific content.

Crowd modeling, as a relatively new field, has attracted extensive attention of researchers in related fields. This technology has made certain progress and need high demands of the authenticity in behavior and the degree of credibility. However, considering about the diversity of the crowd structure and the complexity of the people's movement, the authenticity and complexity of crowd modeling will be the key for most researchers. In is paper, it analyses the people's different behaviors in the crowd when the emergency occurred. with the support of the crowd simulation technology, the FLOCKING by Reynolds [2-3] algorithm and the A-Star algorithm are mainly used in it for describing the motion of the group of human beings, even though FLOCKING algorithms is used for describing animal groups. when an emergency occurs, people usually show a similar characteristics or behaviors as animals, so in this paper, it not only uses the two algorithms for emergency conditions simulated, but also adds the manager agent (coordinating agent) group which is also based on the performance of different individuals in the group during the evacuation, so that a new movement rules is set to simulate more complex behaviors of crowd evacuation in an emergency. These works in this paper can provide a reference for safety management, safety propaganda and education etc.

1.3 Research structure

This article is composed of six parts, there are the following parts: part 1. To summarize the representative research methods of previous researchers. This paper discusses the behavior models of people in macro and micro perspectives, analyses their (behavior models) advantages and disadvantages, and expounds the simulation theory of crowd evacuation in detail. This research also quantifies the crowd behaviour information to simulation.

Part 2. Explain the classification of crowd evacuation models and Agent based group modeling technology. Discuss the agents on the crowd evacuation and the idea of the manager agent are put forward.

Part 3. The basic idea of A-Star and FLOCKING algorithm. Since the FLOCKING algorithm is based on the simulation of animal behaviour and the A-Star algorithm is not so suitable for the model, they should be improved to adjust to the human being's behavior, such as choosing, following, group behaviors, etc.

Part 4. Designed and implemented the simulation system. Simulated the specific environment with smoke diffusion on the Netlogo. To group the crowd with the FLOCKING algorithm, then using A-Star algorithm for the agents to seek for the best evacuation route choice and communication with each other. With the help of the manager agents, we expect that the time of crowd evacuation can be shorten on a fire situation.

Part 5. Analyze the results of simulation and summary the project.

2 Literature review

2.1 Basic introduction of crowd evacuation

Crowd evacuation is an important part of crowd evacuation simulation, dynamic theory of crowd evacuation is the key to the research, and research of the crowd evacuation is 20 years earlier than the simulation in this field. In the late 1960s and early 1970s, many scientists and scholars began to study on the crowd evacuation dynamics, one of the famous work is Fruin.J's work [5]. In his doctoral thesis "Pedestrian and Planning Design", he showed the speed of pedestrians, passenger flow traffic, crowd density in a unit and the space occupied by individuals. He also analyzed the relationship between them through a large amount of data and drew the relation curve graph which described the relationship between the average walking speed of the crowd and the density of the crowd. What's more, in this paper, it introduced the concept of "Level of Service" which is similar to highway traffic theory in the study of crowd movement. In the early stage of the study, the experts and scholars mainly studied on the dynamic behaviors of people and summarized from the observation and then explored the scientific rules of human behavior. In 1971, Henderson L.F[5] did the statistics of crowd fluids. Daamen[6] reported the relationship between the speed of a person's one-way flow and the density of the crowd. G.Keith[7] studied on the crowd dynamics in 2000. Then Kardi[8] found the Pedestrian Flow Characteristics with an image processing data collection and simulation model. William [9] researched on the bi-directional pedestrian flow characteristics. These studies mainly used the regression analysis method to focus on the analysis of the behaviours of the crowd [10].

2.2 Basic methods and models for crowd evacuation

By the 1970s, scholars began using mathematical models to describe pedestrian behaviour, which was mainly aimed at the macroscopic statistical characteristics of pedestrians. Until the 1990s, with the rapid development of computer technology, the behavioural models of various key factors that affect the behaviour of pedestrians began to appear in detail. The development of various kinds of crowd modelling technology has also promoted the research on the authenticity and credibility of crowd behaviour. With the continuous development of crowd simulation technology, many more mature modelling methods and models have emerged in the field of group behaviour modelling.

2.3 Particle system method

The most famous one is based on the method of particle systems. This method is to analyse the characteristics and attributes of the whole group, and then simulating the situation by computer simulation. When making the model comes into true with specific

operation, the individual should be abstracted into individual particles, and the individual motion shall be analysed and simulated according to the principle of global understanding. The main representative models are panic evacuation simulation model [11], cellular automaton model, social force model [12] and so on. France's Eric Bouvier [13] built the crowd motion simulation model. In the case of simple crowd movement behaviour, the method of applying the particle system to analyse and simulate the crowd is suitable for describing the various movements of the crowd. In particular, some sports features in the crowd are more prominent, and this kind of crowd behaviour simulation of the crowd is more likely to show its advantages than other models. However, when the movement behaviour of the crowd is more complex, the usual practice is to make the necessary improvement according to the specific situation on the basis of the simple simulation model.

2.4 Agent-based method

Agent-based method [14-15] is mainly based on the agent-based system which is most different from the particle system method. According to the part of the environment information, the virtual individual can be the one with independent awareness and decision-making ability. By introducing various rules to describe the individual movement in various constraint conditions and the various kinds of sports behavior of the individual, the agents could show a more intelligent community sports behavior than before. Based on the model of intelligent body, individual characteristic parameters can be set up to make the individual's movement behavior more intelligent. Among these models the most famous one is the Rule-based model suggested by Reynolds. The rule model, which originated in 1987, was first proposed by Craig Reynolds and is a typical behavioural model in simulation field. Reynolds called the individuals which are described by the model as "boids", which represent groups of creatures such as flocks of birds and swimming fish. In this model, a distributed way is used to simulate the movement of birds. Each boid moves independently, they maintain the correct position and make the direction by sensing the changes in the local dynamic environment and the rules. Because each boid only has local environmental information not the global information, it is a local control agent only. By applying simple predetermined rules within the individual structure - collision avoidance, speed matching, and clustering to the centre, the technique shows the visually realistic bird group movement. Reynolds expanded his cluster model [16] step further, He proposed navigation behaviour in the model which is used to avoid collision with the obstacles, and established the autonomy of the individual in the form of hierarchical modelling in the crowd behaviour model. So that he extended the crowd model, as a new model, it can simulate the behaviour of the species, and put forward the movement behaviour of the three layers of structure: (1) the choice of the behaviour: strategy, goal, (2) navigation, which means the path planning, (3) movement: Perform the action as the plan. In addition, there are many other behavioural models based on individual rules [17-18]. But they are much more complicated than the mentioned model. When applying a model based on individual rules on a simulation, simple rules can simulate

much more complex group behaviours. However, this method is a local control method, so it is difficult to deal with the non-local congestion or the flow of people naturally. In addition, the formulation of its rules often requires a lot of daily knowledge and experience of people. How to set reasonable rules is very challenging for most researchers.

2.5 Macro-simulation model

The macro simulation model is a kind of early research model. In early time, the development of computer technology was not very well. Scholars discussed the study of evacuation algorithm by studying the collective behaviour data of the evacuation process. The macroscopic simulation model is mainly based on the data of experimental observation. The evacuation algorithm is developed by summarizing and analysing the dynamic characteristic data of a large number of people. Henderson [19], Helbing [20] and Hoogendoorn [21] used the Gas dynamics model to describe the crowd evacuation. Bradley and Hughes [22] provided the flow model to simulate the crowd in 2000.

The early macro models mainly considered about the macroscopic characteristics of the group, and often ignore the microcosmic characteristics of the crowd. At present, microscopic models take into consider about the characteristics of microscopic individuals, and further reflect the macroscopic characteristics by classifying the microscopic characteristics. Due to the lack of computer software and hardware level in the past, computer simulation ability is severely limited. It causes the early macro models to only consider the macro characteristics of the population, and simplify the processing of various important parameters of the model. It also leads to a lack of research on the difference of individual characteristics in one model, the interaction between individuals and the interaction between individuals and the environment. With the continuous improvement of modern computer simulation, the macro model has gradually withdrawn from the research stage of evacuation simulation with the reason that the defects of the model own have greatly affected the simulation quality and effect.

2.6 Microscopic simulation model

In general, we divide the microscopic model into two types: continuum model and discrete model. In the continuous simulation model, the individual's position and individual's movement are continuous changes in the space. In the discrete simulation model, the space of the individual is divided into discrete and equal grids. Representing each individual's position with the grid of the individual, each individual move through the grid according to certain rules [23]. The main representative of continuous model is gravity model, gas dynamic model and social force model. While the representative models of the discrete model are cellular automata model, lattice gas model, domain model and two-step model.

The main difference between macroscopic model and the microscopic simulation model is that the microscopic simulation model focuses on the differences of individual

(such as age, gender, physical condition, learning experience, etc.), the interaction between individuals in crowd evacuation, individual and the environment influence each other and function (such as the size, number, obstacles smoke gas diffuse process, etc.). It sets the microscopic characteristics of these individuals to the various parameters of the simulation model, then It further reflects the behaviour characteristics of the group through the microscopic characteristics of these individuals. Therefore, compared with the macro model, the micro model has higher fidelity and authenticity. It can make more intuitive simulation than the macro one. The micro one can reflect simulation more authentically in the environment of the accident scene, the design of the evacuation channel, the person's psychology, the behaviour state and so on.

2.6.1 discrete microscopic simulation models

In this paper, Discrete microscopic simulation models are used, so it would be introduced first. With the development of modern computer technology, scholars have made a series of significant achievements in the study of total evacuation of people using micro-simulation model. Among them, the typical one is the Cellular Automata (CA) model, which was first proposed by the American computer scientist von Neumann. Cellular automata model is a discrete mathematical model of space, time, and state. It constructs a dynamic evolution system which can effectively imitate the physical phenomena and social phenomena of the real world through the interaction between individuals. It is widely used in economic, military, social, environmental, geographical and biological fields. The working principle of cellular automata model for the safety evacuation of the population under emergency can be shown as follows: According to the rectangular mode, the two-dimensional space under the emergency event is divided into a uniform grid. Each grid is called a cell, some of the cells in the cellular space are occupied by buildings or obstacles, some cells are occupied by individuals, and some cells are empty. Based on the relevant set of environmental system, individuals or groups who have their own attributes and state choose a certain behaviour rules to movement, aiming to simulate the crowd evacuation under the emergency process [24]. The molecular dynamic model proposed by German traffic flow expert Helbing and Molnar is the model of social force, which is also widely used to study the behaviour of crowd [25]. The social force model is based on Newtonian mechanics, which is regarded the person in the crowd as a self-driven particle with geometric characteristics and physical characteristics. In the process of movement, people will be affected by the external physical force and other particles. The social force model is quite suitable for the simulation study of the collision, crowding and stampeding in the relatively small space (such as the exit, stair, passage, etc.) caused by the mass crowd with herd mentality. According to the coulomb's law of physics, the Japanese scholars put forward the magnetic force model. In a magnetic force model, people, exits and obstacles are considered as the magnets in the magnetic field[26]. Among them, pedestrians and obstacles are regarded as the positive poles of the magnetic field, while the exit of safe evacuation is regarded as the negative pole of the magnetic field. The pedestrian who is based on the positive and negative magnetic force

moves towards the destination. So that they could simulate the evacuation of personnel during emergency evacuation and try to avoid the obstacles or the collision. By the way, there are many other works of the Discrete microscopic simulation models: Okazaki,Matsushita[27] and Helbing[28] set the model as the force-based. Blue,Adler[29] ,Muramatsu[30] and Ansgar Kirchner.et al.[31] used the cellular automaton to describe the crowd model. Hoogendoorn[32], Yu,W,J.etal.[33] , Tobias Kretz[34] and G.Antoni[35] built the discrete choice model.

2.6.2 Compared with the continuous model

Compared with the continuous model, the rule of the discrete model is simpler and more conducive to the realization of computer simulation. The calculation is faster and the simulation is more efficient. However, the discrete model has little consideration for the interaction between individuals, and the simulation of individual behaviour is simple, and these lead to the difficulties to accurately describe the factors of crowd evacuation. The continuous model is better because it focuses on the interaction between individuals, and the behaviour description of the individual is more accurate. But the continuous model reflects the continuous change of the individual in space, which is more demanding for computation and is not conducive to the simulation of computer simulation, which makes it more difficult to realize.

2.7 Literature of fire simulation

The simulation study mainly uses the computer simulation software to simulate the whole process of the safe evacuation for study further on the aspects of crowd evacuation. To compared with the other methods for research, the cost of simulation study is lower and it is convenient to do so. As far back as 1909, there were scholars in the United States on the study of personnel evacuation [36]. In 1972, Wood in Britain published an article entitled "The behaviour of people in Fires" by investigating. The behaviour of 952 Fires and 2,193 people who had experienced those fires. It pioneered the study of specific behaviour in the fire [37]. In 1995, Bryan counted the effects of gender on the first behaviour of people in a fire [38]. In 1996, the American Barilo survey and collected the age, gender and ethnicity of the victims of the 727 Fire in New Jersey in the late 1980s and early 1990s to analyse the factors of the death [38]. In 1999, the Australia Brerman investigated about 100 fire safety accidents in Victoria, Australia, from 1990 to 1995. The basic data of the victims were obtained, the proportion of the age and sex of the victims was calculated and the impact of the escape of the alcoholic was discussed [39]. In 2008, Filippoupolitis et al [40] simulated building evacuation which is based on the agent-based model during a fire. The similar researches are Shi et al [41] Tang and Ren [42], Yang et al[43] in the year of 2009 and 2011.

2.8 Summary

In the study of this paper, the density and quantity of the safe evacuation group are large, and there are thousands of individuals exercising at the same time. In the case of continuous model, each individual's movement rule corresponds to a set of differential equations. This is a high requirement for computing power to the computer. Simultaneously simulating the various movements of hundreds of individuals, which has almost surpassed the computational power of ordinary PC, Therefore, there are many problems and difficulties in the application of continuous model, especially in the implementation of simulation. On the other hand, the discrete simulation model, such as the representative Agent based modelling, can discretize the continuous state of individual actions. It greatly reduces the computation of the computer, which is more conducive to the realization of computer simulation. What's more, if the model design is reasonable, it also basically achieves better simulation results as the complex one. Therefore, under the consideration of all aspects, this paper will utilize Agent microsimulation technology. It saw each person in the crowd evacuation as one agent. Based on Agent based modelling, crowd evacuation model was established to simulate safety evacuation.

3 Research Methodology

In this paper, an agent based micro-discrete simulation model is used to simulate the crowd evacuation simulation. The algorithms which are used in the model are Flocking and A-Star algorithm. Netlogo software would be used as the simulation software.

3.1 Discrete simulation model

Due to the limitations of macro simulation model, people began to focus on micro models to seek for simulating the evacuation process which is based on the individual's behaviour decision. During this period, computer technology developed rapidly, which provided great convenience for the study of this subject. The microsimulation model is divided into discrete simulation model and continuous simulation model. Discrete simulation models require less computing power and are more suitable for simulating the evacuation of large numbers of individuals in thousands of units. The continuous simulation model requires very high computational power, which is suitable for small-scale evacuation simulation, and the results are more realistic than the discrete ones. Discrete evacuation simulation is used in this research, the discrete simulation model will be introduced.

Discrete simulation models are also called cellular automata models or lattice automata models. This model was first proposed by Von Neumann. The building plane is divided into very small grids, each grid is a square cell, and its size is generally the step length of the proposed person. A lattice has only two states at a time, either occupied by people

or buildings, or empty which can be used as path selection. In this way, the status information for each point on the grid can be queried with a number. In the simulation, each point can select the other eight squares around it as the path, and according to its own rules of behaviour, it is determined to move to the non-congested lattice. In the grid, the individual's coordinates can be set as the (x, y) , so that all eight other grid coordinates can be easily set as $(x-1, y+1)$, $(x, y+1)$, $(x+1, y+1)$, $(x-1, y)$, $(x+1, y)$, $(x-1, y-1)$, $(x, y-1)$, $(x+1, y-1)$. The value I represents the state of the point, and if this value is equal to 0, the point is not occupied by other objects and can be used as path selection. While once this value is equal to 1, which means that the point has been occupied and cannot be chosen as a path. If multiple cells are available, the individual's choice is to refer to which grid is closest to the target exit point. When the individual passes this step, it is important to redefine the state of the individual according to his state and the state of the surrounding grid. In this model, time and state are discrete.

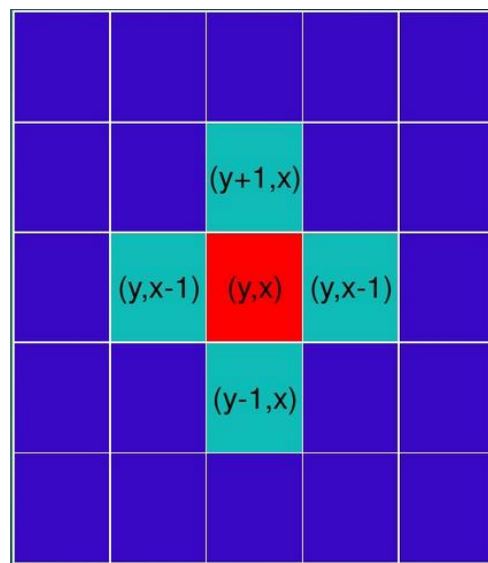


Figure 1 CA model

The focus of this approach is on the individual which needs to be selected. In the case of more alternative paths, it is often judged that the decision has to be judged to reach the target. And in the study, the metamodel model was found to be able to move the map grid in eight directions when selecting the path. Then the individual can only choose 45 degrees Angle or 90 degrees Angle as the direction choice, this is very unrealistically in the process of real simulation. A linear representation is proposed to improve the single defect of the selection direction of grid representation [44]. This article will take a similar approach to emulation, and the specific implementation methods will be explained in the later chapters.

3.2 Agent and Multi-agent

3.2.1 Basic concept of Agent

Agent is widely used in different disciplines and fields, and the application has different

emphases. So that the Agent doesn't have a very clear definition[45]. The core concept of Agent is the autonomy of Agent. The agent was applied to the field of artificial intelligence in the early years. With the development of Agent technology, Agent has been gradually applied to other research fields. In short, Agent is a self-directed entity that imitates human behaviour and characteristics. In 1995, Dr Wooldridge, a leading British Agent, had defined Agent as a computer system. Under the setting environment, the system has its own rules of behaviour and learning ability, which can adjust its state to make decisions according to the goals set by itself or the system. Dr Wooldridge et al. also proposed the classic strong and weak definition of Agent, it was widely used in various research and application fields of Agent system.

3.2.2 The classic strong and weak definition based on Agent

Some scholars have proposed that Agent has the attributes of the weak definition of classic Agent and the properties of interactive cooperation ability. The interaction and cooperation ability of an agent is related to the intercommunication and interoperability of multi-agent. In general, the Agent itself has a complex behaviour or action "warehouse". When the Agent examines and analyses the external environment and its own state, the Agent will choose the actions in the "warehouse" to be exported, the actions or the movements are according to the environment or the target set by itself. Through these actions done by the agents, the external environment is affected to achieve the goal. Of course, the external environment cannot be completely fixed. The complexity of the environment determines that it is dynamic and constantly changing. This kind of environmental change will affect the Agent. If the Agent fails to adjust the strategy and behaviours timely, it may fail to achieve the goal. Therefore, the Agent needs to use its own autonomous capability, social ability to adapt to the changes of the environment, and even eliminate the influence of the environment on itself. This is the interactive, dynamic and continuous learning process of the agent. After learning the basic knowledge of Agent, these are the abilities of the agent:

(1) Autonomy

The agent has a strong ability of self-control. This ability makes it difficult for the external environment to affect the agent directly.

(2) Responsiveness

The agents use their own sensors to respond to the environmental.

(3) Activeness

The Agent does not simply passively accept the influence of the outside world, but actively changes the behaviours according to the environment or the target set by itself. This is also an interaction with the outside world for the agents

(4) Sociability

Agent cannot exist independently from the system, and it has the same social characteristics as human or many organisms. The social behaviour ability of Agent in MAS system is its social manifestation. Just as the language and behaviour habits formed during the long evolution of human society, Agent also establishes an interactive and language mechanism in the system and relies on this mechanism for

interactive activities.

(5) Intelligent

The agent was applied to artificial intelligence in the early days, the Intelligence is the feature of the agents, and the Agent with strong intelligence is equal to the agents with the ability to learn and adapt to the environment. When the Agent is applied to various fields, it may also have other abilities and characteristics beyond the basic capabilities.

For example, when an Agent is applied in the field of physics, it can reside in a certain number or physical environment for information perception and feedback. It is called as the feature resident. Of course, these additional capabilities and features of agents are based on the basic capabilities of the Agent.

When we study the evacuation of crowd during emergencies, we will use agents to simulate the people in the real world. Therefore, it is usually given to the agent to think like a person and act like a person with desire, demand, belief, etc. For example, in the Agent simulation system, we will give the Agent a thinking attribute to find a feasible method or escape route in the shortest time to escape from the dangerous situation as soon as possible. The environment is very important for the agents. According to the environmental characteristics of agents, the environment is generally divided into four categories:

(1) Knowability and Unknowability

If the Agent can sense the full factors of the current environment, or be able to perceive the various information which is associated with it in the current environment, then the environment is effectively knowable for the agents. An entirely knowable environment is convenient for agents because agents can obtain sufficient information about the environment. Thus, high-quality decisions and behaviours can be made smoothly. If it is not knowable for the agents, the agents will fail. For simulation designers, they always try to obtain the most comprehensive and accurate environmental parameters to ensure the real and effective simulation system.

(2) Certainty and Uncertainty

Generally speaking, in a knowable environment, Agent can clearly know all the factors in the environment as well as the next movement about itself. But once agents lose their judgment about the environment and worry about environmental changes, the situation is uncertain.

(3) Static and Dynamic

In a static environment, agents can obtain accurate information about the current environment. By the way, the Agent does not need to scan the state of the environment repeatedly while performing the action, nor does it worry about time in this kind of situation. While once in a dynamic environment, the agent cannot obtain accurate information of the current environment, and needs to explore the environment before performing the action.

(4) Discreteness and Continuity

Discrete environments represent a finite number of distinct discrete situations,

while continuous environments represent an infinite number of undistinguished continuous situations. In short, most real environments are unknowable, uncertain, dynamic and continuous. In general, the environment in reality interacts with the outside world in a lot of complex energy and information. We usually call this environment an open environment. The constant change of environment determines that the interaction between Agent and environment is real-time. In other words, the real-time interaction between Agent and environment is the interaction between environment, time and Agent. Time is a very important factor in the evacuation model. Generally speaking, agents need to make judgment decisions in a very short time. Therefore, the study of Agent can not only focus on Agent behaviours only. Instead, they should combine the environment, time and other important factors to master their characteristics, interaction rules and language and behavioural goals for the agents.

3.3 Multi-agent System

Although agents are very powerful to do anything, an individual agent cannot handle large-scale and complex problems. Therefore, we need to make an interactive group of agents in a virtual environment to solve problems in the environment or System, this is the simulation of the MAS (multi-agent System).

There are many problems involved in MAS. Such as the reasoning of individual agents; Assignment of tasks; Multi-agent planning; The consistency of goals and behaviours; The identification and digestion of conflict; To establish other Agent models; Communication management; Resources management; To adapt and learn; The security and load balancing of the system and so on. MAS is a complex system which has different relationships between agents and agents. Such as the relationship of equality and opposites, we regard it as the structural relationship between the agents. Generally speaking, the structural relations between the agents in the environment are relatively stable. Once the relationships such as the competition, negotiation and cooperation happen between agents, they would be called as the behavioural relationships. When agents are in conflict with each other, it is necessary to establish the interaction mechanism between the agents to form the corresponding interaction model.

3.3.1 The interaction in MAS

When the MAS is driven by group goals, the interaction and interaction between agents is called Agent cooperation or cooperation. There are usually five types of collaboration between multiple agents: Collaborative agents, selfish agents, totally selfish agents, totally collaborative agents and the mixed type agents with selfish and collaborative. In general, scholars view collaboration as a natural behaviour of agents, it is the natural behaviour that the agent displays to adapt to sociality. In the process of the agent

collaboration, one Agent will make a request to another agent to achieve the intended target. The requested agent displays a different response to each other's request. The requested agents may accept the messages or reject them, they may "not respond" or also make "new Suggestions". In this way, the individual agents complete an interactive process. From the above, it can be clearly seen that the agent research focus on the individual agent, which does not consider about the target of the agent group or the cooperation with the agent group. However, In a complex multi-agent collaborative environment, the agent cannot be simply classified as the individual agent. They may be the Multi-agents. The direct judging between individual agents and multi-agents is the attribute and demand of the system or environment of the agents.

In the process of crowd evacuation, the cooperative ability of Agent is used to simulate the behaviour of the crowd. Instead of defining the properties of each Agent, we classify the same or similar individuals. We would research the cooperative relationship with the similar groups.

3.4 The behaviours of the group

The phenomenon of group behaviours can be seen everywhere in life, such as the large number of spectators in stadiums and shopping centre. Even in the nature, the migrating birds is also the group behaviours. The simulation of group behaviours is mainly about the factors of the behaviour and movements of the group behaviours under certain conditions in the situation. Based on the study of this, the simulation model of group behaviours is established to make a more realistic simulation of the various movements of the group. The rapid development of computer science has made the group movement simulation technology unprecedented progress. Then it also plays a certain role in the development of the agent-based modelling of group behaviour.

Group motion simulation technology is developing at a high speed and can be used in many fields. Especially in the field of public safety, the application of group simulation technology can be fully demonstrated. For example, in the design process of various facilities in many large venues and in public entertainment areas, it is more useful than other technologies. The analysis and demonstration of it can greatly simplify the design of many unnecessary links, what's more, it can effectively save a variety of resources and realize the actual application of technology. Group motion simulation technology has a great advantage in the aspects of directness, flexibility, economy than other technologies. It is very useful for the further study of the group motion study.

With the continuous improvement of crowd movement simulation technology, especially the expansion of simulation application. the research on large-scale crowd movement simulation technology has gradually become the key of virtual modelling simulation. In the study of group behaviours simulation, how to model the crowd movement and how to simulate the crowd movement become the key of the study. In the implementation of specific modelling, we should think twice about the various movements of the crowd. While the effect is the key of the computer simulation

technology we should considerate in the process of simulation. Until now, the research work of large-scale crowd sports simulation model is still in its infancy, and much work remains to be done. Considering about the complexity of the motion behaviour of the crowd and the uncertainty of various behaviour of the crowd in the process of movement, there is not a relatively complete, universally applicable crowd motion simulation model for all kinds of crowd. Although the crowd modelling technology can promote the establishment of the simulation model of the crowd, there are some difficulties in the crowd behaviours simulation with the increasing of the population size and the complexity of the scene.

3.5 Methods to set the path for the group movement

With the development of crowd simulation technology, the research of group behaviour has been paid more and more attention by many scholars. The emergence of virtual reality technology has greatly promoted the development of research work in group behaviour. Among them, the application of virtual reality technology to large-scale crowd simulation has also promoted the progress of the field of crowd behaviour modelling. Large-scale virtual crowd simulation mainly involves crowd simulation and path planning. The simulation of the crowd belongs to the simulation of the virtual scene, which is easy to realize. Path planning is a path to avoid obstacles in the process of crowd movement and is also the key to the research. It is mainly divided into two aspects: global path planning and local path planning.

3.5.1 Global path planning

Global path planning is a planning scheme for an efficient path from starting point to destination. By focusing on the information of the virtual environment and various information about obstacles, a global path planning will be set on the basis of comprehensive sharing of information resources. Until now, this technology has been improved well.

In the process of global path planning, the design of artificial potential energy and grid method are fully utilized. The two - dimensional motion scenes are divided effectively, and the static obstacles and dynamic obstacles in the scene are clearly defined. Thus, the energy of the individual through the small region is calculated. The specific calculation formula is:

$$F(i) = a * s + b * n + c \quad (3-5-1)$$

s is the area size of this area for static obstruction, N is the number of virtual people within a small area. a is the drag coefficient of an obstacle. b is the influence coefficient of the density of the virtual person on the direction of human movement. c is the time it takes to get through this little region. In the process of specific path planning, it is assumed that the selected region should be the starting point of the path planning. So the weights coefficients of the four directions around the starting point can be

determined. In this way, the shortest path of the individual motion can be determined by the position of the smallest node in each step path planning.

The global path planning process is a process of information sharing. When the collision is predicted, it can effectively utilize the Shared information resources to increase computational complexity. However, this path planning approach is not ideal in terms of computational complexity and further improvements of the path planning approach are needed. So, the path planning process is more suitable for the small groups.

3.5.2 Local path planning

The local path planning method has more stringent way to simulation than the global path planning method and the implementation process of the local path planning method is more complicated than the global path planning method. For example, in the process of local path planning, obstacles can be designed to avoid, the choice of strategy can be chosen to determine the movement characteristics of the crowd and the behaviours. The research on this aspect is the hotspot of the research of virtual crowd behaviour. Most of the work is done around collision avoidance. In the specific path planning, there are clear rules for the individual movement behaviours. These are briefly introduction below:

(1) To avoid obstacles

The modelling of this behaviour is achieved through raster method, So the detection method is relatively easy. In the concrete implementation of the method, it is necessary to define the state of the grid and the individual motion. Then by calculating the corresponding two-dimensional array, the path of the individual's next movement can be determined.

(2) To move along the wall

When the movement environment is simple, the path planning process of the virtual individual is easy to realize. However, when the environment becomes more and more complex, the individual will often walk around in a certain place in the simulation process of the virtual individual. Although the optimization of the algorithm has been done to add random perturbation to improve the situation, the simulation results are not good as expectation. To solve the problem, agents in this model would be set to go along the wall.

(3) To avoid the others

During the process of moving around, the agents would inevitably encounter with other agents in local path planning, the usual strategy is to avoid other agents. the agent can find a path to the target in a more complicated environment. This can effectively prevent two individuals who are very close to each other from stopping as waiting for each other to get out of the way. This kind of path planning can improve the speed of the movement of the crowd.

(4) To run towards the goal

After implementing some of the strategies described above, virtual agents are usually able to do the basic behaviour. When the virtual agent is moving forward

gradually through a one-step movement in the situation, there is also a strategy for them to move towards the target (evacuation exit). Thus, the agent has the overall goal orientation. The realization of the goal requires that the agent should “consider” about every step of itself. In addition to taking into account the information about itself and the surrounding environment, there is also a need to consider the interrelationship between the individual and the target. Only in this way, the local path planning of the individual can be realized effectively.

The simple act described above is the cornerstone of complex behaviour. Based on these simple behaviours, a variety of complex group movements can be formed. Unless there is only one behaviour needed in a simple world, it makes no sense for the agent to constantly only one behaviour. In fact, there is impossible in the real world. The real group movement is often presented in the combination of a variety of simple behaviours. There are usually two forms of combinatorial behaviour for the group. One is that when the surrounding environment changes, the agent converts between several behaviour modules in a circular manner. The other is that the various simple movements are grouped together in the form of group movements. In this way, combinatorial behaviour is actually parallel group movement.

Typically, the combined behaviours include crowd path following, leader following, unaligned collision avoidance and queuing(at a doorway), When there is a needing for the combining behaviour, the agent calculates the next step of simple behaviour to get the next movement of the combined behaviour. May be some weighted coefficients will in the process.

3.6 A-Star algorithm

In the process of evacuation, the group of human beings should search for the exit to get out. we consider the application of A-Star algorithm in this crowd model. The algorithm is used in this paper to guide the path selection and following behaviour in the process of the crowd evacuation. A-Star is a kind of Search method which is a problem solving method in artificial intelligence and the priority relation of knowledge in solving process is determined by the search strategy.

The search strategy is divided into the unguided brute force search and the heuristic search using the empirical knowledge. A-Star algorithm is the heuristic search. By using the enlightening knowledge associated with the problem, the specific information will be used priority for the search process when solving the problem. Selecting the best location and then search from that location until finding the target, this process is called heuristic search. In heuristic search, estimation of location is very important, and different values can be applied to different values [46]. In the heuristic search, the search direction is controlled by the design function which need to select the node of next time. The design function is the so-called evaluation function. It is an estimate of

the minimum path cost from the starting node to the destination node via node n .

A-Star algorithm was developed in 1968 by Hart 和 Nilsson. It can guarantee the

shortest path. The basic idea of a-star algorithm has the following three points:

(1) it is assumed that there is an inspiration function (The estimated cost of node n to target node). It is a real value function of the node state and can help determine the next best node to be extended.

(2) the next node to be extended is the node whose value is the smallest. (in this case, assume that you extend a node to produce all its subsequent nodes)

(3) if the next node to be extended is the target node, the search process terminates.

3.6.1 The application of A-Star algorithm in crowd evacuation

The lead mode and the searching mode are the most important problems in the crowd evacuation. These two issues would be analysed below:

The "lead" mode in movement

"Leading" is not the feature of the A-Star algorithm. So we should adjust the al
Make a simple simulation of this "leading" process, Imaging that the whole group is hiding in the nest, and one of the leaders is going out and looking for food. Other individuals also go out of the nest at intervals and follow the leader. When an agent comes out of the nest, this agent would go straight to the current position of the agent who is leading, and no longer expends the extra effort to search for the line. We set the first one to be red colour, and the process of searching the route is marked out in blue colour, followed by the followers in yellow colour. Each follower follows the forward of the previous leader. In this way, it is clearly that the path of the follower is greatly shortened when the follower reaches the target. It's important to note that not every yellow agent has the same path, the later the followers come out, the shorter the path that comes out later.

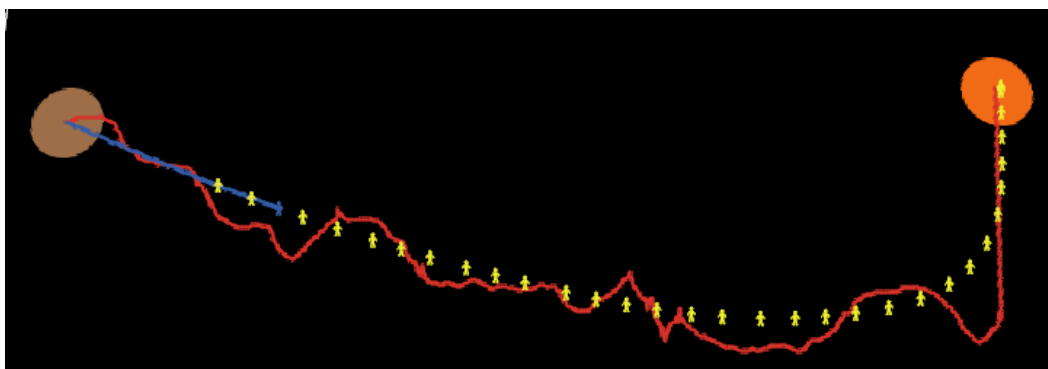


Figure 2 Ant line

This idea can be added to the A-Star algorithm to make the target that leading feature for the coordinating agents.

The searching mode in the movement

In A-Star algorithm, Nilsson proposes a well-known graph search process

GRAPHSEARCH, in which two tables are needed: OPEN tables and CLOSED tables. The OPEN table stores the device nodes that have been calculated and evaluated in the graph the open table including the nodes and the father nodes)

The CLOSED table stores the device nodes that have been accessed and logged in to the search information in the diagram. (the closed table including the number, nodes and the father nodes)

Once the open table is blank or the nodes in the table is the final node the agent will stop and get their target. If the node is not the final one the smallest one in the open table will come to the closed table and to be select as the final node or not ,if it is the final node, we get the target if it is not ,we will back to the open table again.

The basic flow of the algorithm is as follows:

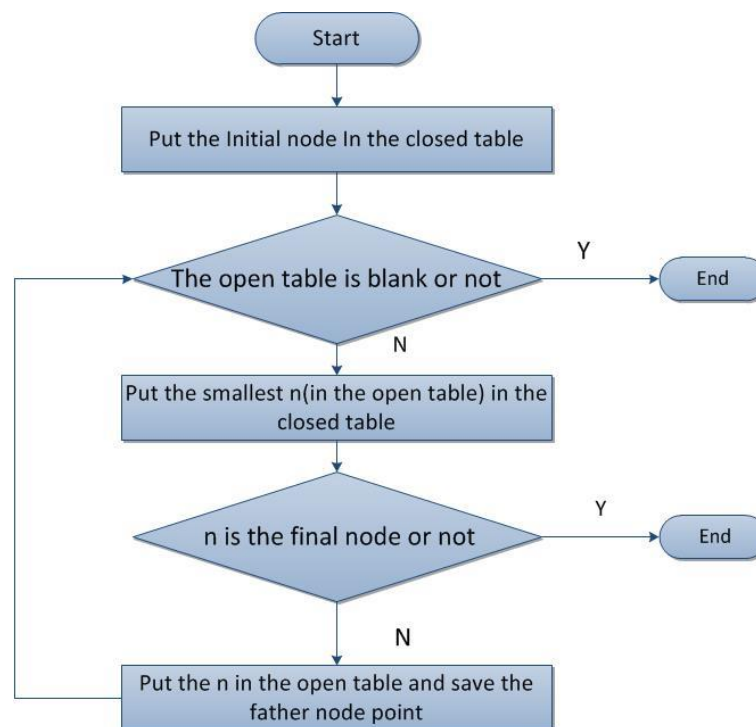


Figure 3 A-Star algorithm flow

3.7 Flocking algorithm

FLOCKING algorithm was presented by Craig Reynolds in 1987. The algorithm is mainly aimed at the simple aggregation behaviours of birds. And the simulation model is based on the related research and the interaction between individuals in the flock. while the established model is relatively simple, but for it provide a valuable reference for the more complex swarm behaviour model. Generally speaking, FLOCKING algorithm is used to simulate some simple animals swarm behaviours and simulate well for groups such as flock and fish. Algorithm is effective in controlling the behaviours of the group.

Many new rules of behaviours and various models of improvement flocking algorithm

based model is built after the flocking algorithm has implemented a simple simulation model of crowd behaviours. These rules and models are beneficial to the analyse and descript the behaviours and relationships among agents in the group. Analysing the local attraction and repulsive force of the neighbouring agents in the group, the researchers established the separation and aggregation rules of the movement between individuals [47]. Moreover, on the basis of analysing various behaviours of agents in the group, the agent in the group has been added to the rotary force to avoid the obstacles [48]. It has made the agent more intelligent and has made some improvement in the reality simulation. In addition, when formulating rules are setting for group movement, if only behaviour of the individual is taken into consider there will be a lot of mistake in this kind of model. the rules of crowd behaviour proposed by Tanner [49] are more prominent in this regard. Because every individual has a certain code of behaviour when the rules are enacted, but it doesn't necessarily apply to the whole, In a word, in the field of virtual reality, FLOCKING algorithm play a role as a new members, but the algorithm has been successfully applied in many areas and has an obvious advantage over other algorithm. It is believed that with the continuous improvement and improvement of the algorithm, the more advantages of this algorithm will be fully found.

3.7.1 The basic rule of FLOCKING algorithm

In 1987 Reynolds put forward the earliest FLOCKING model, there are three basic rules in the model for the member. Based on the introduction of three basic FLOCKING control rules, the first computer simulation of the FLOCKING phenomenon is derived. The three basic rules in the model are: separation (Separation) rule; Alignment (rule); (Cohesion) rule. The three basic rules are described in the following:

Rule of separation: in order to avoid collisions with neighbouring intelligent agents, intelligent agents need to keep a distance with the neighbouring agents.

Line rule: the direction in which all agents and their agents in the field are in the same speed direction.

Aggregation rule: to keep all agents in the same direction with the average location of all agents in the field, which makes the agents cohesive and easy to keep the queue tight. Considering that the behaviour of the crowd in emergency evacuation is similar to the simple emergency behaviour of animals. The basic rules of FLOCKING algorithm are improved and expanded further, so that it is more suitable for the study of crowd evacuation simulation. The basic rules of FLOCKING algorithm are also demonstrated in the simulation experiments of crowd evacuation. In order to show the authenticity and credibility of the simulation, the agent must control its speed of the movement in the crowd. For each individual, they have the space as the following picture in which a triangle would represent an agent, each agent has a visual distance and visual angle (including visual distance and visual angle as well as the Vision Range which can be represent by the visual distance and visual angle), various parameters such as speed, angle. They also have the acceleration range (Acceleration Range. R1, here we put the

visual range as the acceleration and deceleration range are represent as the Deceleration Range, R2) which used to define the range of speed.

Based on the three basic rules of FLOCKING algorithm, this paper puts forward the calculation formula of velocity changes are as follows:

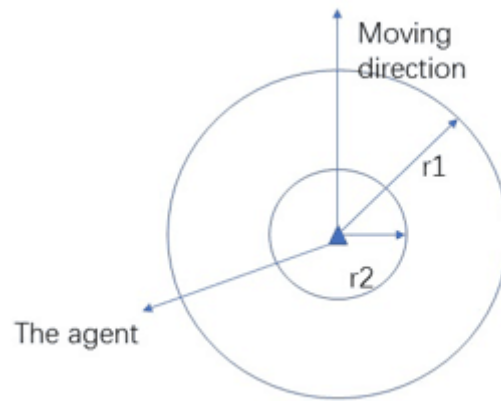


Figure 4 The scope of the victory

$$v(t) = v(t - 1) * (1 + \alpha * dv)$$

Note:

$v(t)$: current speed of individual movement

$v(t-1)$: the speed of the individual's last step

dv : the amount of speed change in an individual movement

Speed adjustment parameter, if $\alpha > 0$, try to accelerate the speed of the motion. If $\alpha < 0$, then slow down the speed of the motion.

Among them, in the process of achieving the phenomenon of speed change in crowd evacuation, it also integrates the 3 basic rules of the traditional FLOCKING algorithm, which is not introduced in detail here. The crowd movement process of actual individuals will vary according to their environment, their speed and ultimately queuing. All of the phenomenon would exist in the simulation.

In speed adjustment mechanism, selection of parameters should be close to the real scene or environment, individual movement velocity and velocity variation should be able to reflect the structure of population and the parameters of the individual characteristics. In order to maintain the continuity of motion smoothness and better simulation effect, the absolute value of alpha cannot be selected is too large, in this simulation experiment, when the acceleration is alpha is set as 2, when deceleration alpha is set as -1.2.

3.7.2 Adjustment mechanism

The principle of speed adjustment in the course of movement is introduced, and the speed adjustment process is summed up and the principle diagram of speed regulation mechanism is obtained.

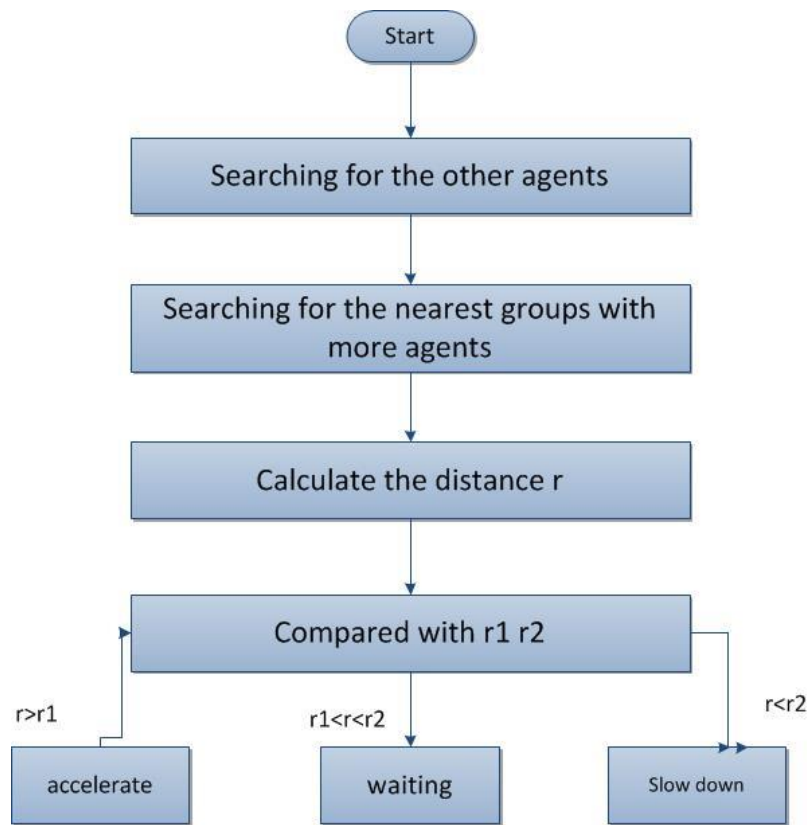


Figure 5 Flocking algorithm flow

In the speed adjustment mechanism shown above, individuals first need to search their own visual range for other individuals, If there is no other individual, then the individual accelerates; If there are other individuals, then the individual needs to continue to search for individuals within the visual range of all individuals who are closest to themselves, Then calculating the distance between the agent and the nearest agent, this distance respectively with the acceleration range and individual deceleration range are compared, if it is bigger than the acceleration range, so the agent will acceleration, if it is the number between acceleration range and deceleration range, then the individual will be waiting, if it is less than the deceleration range, then the individual will slow down the speed. The schematic diagram shows how the individual changes in speed during the course of the application of the FLOCKING algorithm. The simulation experiment of this principle is carried out in the experimental simulation part of this paper, and the results show that this principle can reflect the characteristics of the individual's velocity in the process of movement.

Simulation Design

4 Development

4.1 Agent-based modelling design

According to the characteristics of the MAS system, we conclude the interaction of multi Agent in the evacuation model into the following three stages:

- (1) Demanding: An individual or group of agents analyse information transmitted by an external environment or other Agents. According to the system goals and their own status, interactive requirements are put forward to prepare for the next phase of decision-making. But in different time and stage, this interaction demand will also change differently. For example, in the early stage of the evacuation, the interaction demand of Agent was mainly to inform the disaster information, to ensure that all agents obtained real information. In the middle of the evacuation, the interaction demand of Agent is mainly to select the most suitable evacuation route and ensure the evacuation of person as soon as possible. In the later stages of evacuation, the Agent's interaction needs are mainly the mutual assistance between the evacuees or the search for possible one who were not escape form the fire.
- (2) Planning: Planning stage is the most important stage of multi-agent interaction. The main task is to make decisions according to the current state. Agent adjusts its own state in time according to the decision, and exerts the autonomy, learning ability and social ability of Agent to carry out the interaction between the Agent individual and the group. For example, in the evacuation process, Agent will be based on the environmental information and other Agent transmission of emergency information such as the current state to make decisions, to find the most suitable for export and select the most effective evacuation route as well as to ensure evacuation of subway accident in the shortest time. During the evacuation, there will be a large number of interactions behaviours between Agent individuals or groups, such as advice, consent, rejection, and counterproposal. It is worth mentioning that we need to specify the different types, quantities, and relationships among agents, individuals or groups during the planning.
- (3) Evaluation: After the operation of agent has been completed, the analysis of the results of the operation and the process of the previous stage can be carried out to evaluate the behaviours of the whole MAS and agent individuals or groups.

4.2 Crowd division and Agent group interaction mechanism

This paper divides the people who have escaped from the evacuation into three types of Agent groups:

The first type, coordinated Agent group or manager agent group, they are familiar with the environment, and have certain emergency escape knowledge and skills or the ability to communicate with each other to find exports. In the evacuation process, the coordinated Agent is not only to consider its own escape, but also to play the role of

conductor coordinator in the field evacuation, to help other groups to escape as soon as possible.

The second type, the reverse agent group: This kind of crowd may be influenced by many factors when they are evacuated, and they don't choose to usual way as other person, but the way where few people would choose.

The third type, following agent group, these kinds of groups tend to follow large groups during evacuation, forming small groups themselves and then following coordinated groups.

Therefore, based on the above three types of Agent groups, we built the basic attributes of the Agent-based model. It includes the following four aspects:

Roles, which represent for the different Agent groups;

Familiarity, which reflects the familiarity of different Agent groups to the environment;

Ability, it reflects the ability of different Agent groups, such as reaction speed, walking speed, etc.

Interaction, which reflects the interaction rules and states between different Agent groups, such as interaction purpose, initiate interaction, response interaction, information input and output process processing. According to the characteristics of different Agent groups, we have established the interactive protocol diagram of the different Agent groups in MAS. After the emergency, the information was released to different Agent groups. After receiving the information, the Agent groups can make decisions based on the current environment and their status, thus producing the next target of action. The internal and group of Agent groups are oriented towards the goal, using the experience of Agent itself, and establishing interaction with learning ability through adaptive features. The interaction process within the system will finish until the target is completed, and the entire interaction also finished.



Figure 6 Interaction protocol of agents

In the whole interaction process, the coordinated Agent group is the main body in the

interaction process. They can give priority access to information and promptly notify other Agent groups. They initiate coordinated actions that affect the entire interaction process.

As shown in the figure, the number 1 indicates that the coordinated Agent group gets the outside information and starts the coordination work; the number 2, 6, 8 indicates that the coordinative Agent sends information to other groups for evacuation suggestions; the number 3, 5 indicate that the agent will receive evacuation proposals; the number 9 represents refused to or not to respond to the evacuation; the number 4, 7 indicate that the agent will follow the evacuation proposals and confirm the implementation of recommendations; the number 10 indicates that the agents confirm not to execute the evacuation proposals.

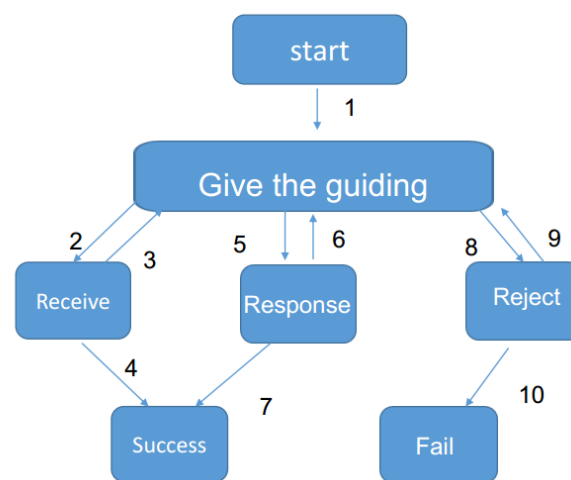


Figure 7 The working process of the coordinated agent

4.3 The design of the crowd evacuation model

In the model built in this paper, we will mainly show the following basic characteristics of the crowd evacuation:

- (1) in the evacuation process, the population tends to choose the most recent and safest path to evacuate.
- (2) during the evacuation process, the crowd generally keeps moving and will not easily change course.
- (3) some groups will behave as groups and follow the group behaviours.
- (4) people generally choose the exit that is currently identified, and even if they spend a lot of time waiting at the exit, they are reluctant to choose a new exit.

4.3.1 Environmental modelling

In the safe evacuation model, we abstract the SWANSEA MARKET environment into a two-dimensional grid plane and set each grid to a square cell of equal size. For each

cell, we define the following properties:

- (1) whether the cell can accommodate pedestrians or not
- (2) whether there is someone in the cell or not.
- (3) the length of the shortest path to the nearest exit or not

For each cell in the model in the original setting, there can be only one of the following three states:

- (1) The cell is occupied by one person.
- (2) The cell is occupied by obstacles.
- (3) The cell is empty.

For an agent, an Agent can only occupy a cell at any time, so the location of the Agent can be determined by the cell it occupies. We have simplified the specific environment of the Swansea market. In the picture, the black area is the area where people can move anywhere, The green area is the wall of the market and pedestrians cannot occupy the grid or pass through it; The brown area indicates a variety of obstructions and pedestrians cannot occupy this kind of grid or pass through it; The white area is the occurrence place of the accident, such as fire source, explosion source, source of toxic gas, etc. Because the pedestrian does not overlap, so we set the cell in the model to be occupied by only one pedestrian, According to the principle of ergonomics, the human body can be approximated as a long axis of 0.61M, with a short axis of 0.456M.



Figure 8 Initialization environment

Furthermore, considering the average occupation area of pedestrians under crowded conditions, the model of this paper set the individual of the pedestrian into a square of $0.4 * 0.4 m^2$, and will not produce deformation and overlapping, Therefore, each cell of the model is also defined as $0.4 * 0.4 m^2$ square, to ensure that each cell can be occupied by only one pedestrian only in the setting model.

Human walking modelling

In the evacuation model, the setting the modelling of the evacuation crowd is the key of the model, while setting the walking modelling of the people in the evacuation is the key of setting crowd modelling.

Basic rules for walking

The rules include: if there is no obstacle in the forward direction, the agent will directly toward a direction; if there are the obstacles or the other pedestrians the direction of the agent will be changing; the agent will not affect by other pedestrians in his back; when there is a clustering or blocking, the speed will reduce or even become 0; Pedestrians generally do not allow for transcendence.

Basic definition of walking

Based on ergonomic principles, we can think of the human body as an oval basic unit, the long axis is 0.61M and the short axis is 0.456M. and the standard walking speed is V [m/s], the View is View[m], the destination is target, and the direction of the individual is My Direction. Among them, V has been set above. View refers to the identification of obstacles around pedestrians. View describes the scope of the radius of the [m], View Angle is from 0° to 300° . It can be shown clearly in the following picture:

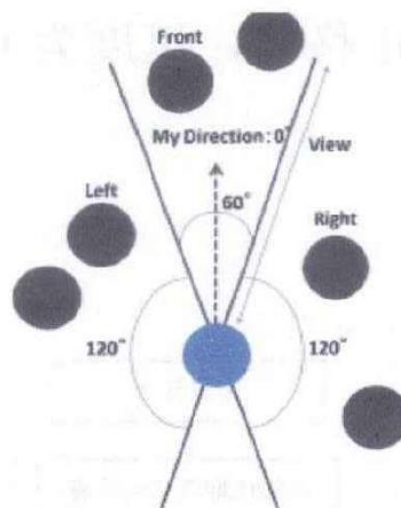


Figure 9 View of the agents [50]

Speed and walking rules

Walking rules: First, there are no obstacles or other people in the front View [m], and the walking speed V is moving in the direction of My Direction

Second, if there are obstacles in the front View [m], and there are no obstacles in the left or right, they can choose turn right ($\text{My Direction} - 90^\circ$) or to turn left ($\text{My Direction} + 90^\circ$) Direction.

Thirdly, if there are obstacles in front, left and right, the pedestrian will wait in place and not move.

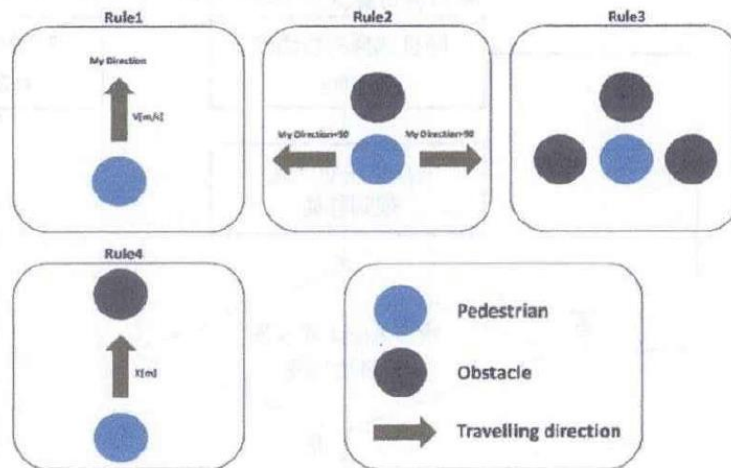


Figure 10 Walking rules

In general, pedestrians move in a speed of about 1.2m/s. pedestrian walking speed is mainly affected by the clustering speed, and the moving of the clusters are mainly affected by the unit in space within the population is the influence of crowd density [50]. Therefore, the relationship between walking speed and cluster density is:

$$V = -0.0025p^4 + 0.0058p^3 + 0.0844p^2 - 0.5076p + 1.7607$$

Among them, p refer to person density(person/ m^2) According to the existing research results, pedestrian walking speed will be significantly reduced when cluster density is greater than 5 people/ m^2 . In this model, if the cluster density exceeds 5 people/ m^2 , the pedestrian will stop.

simulation flow

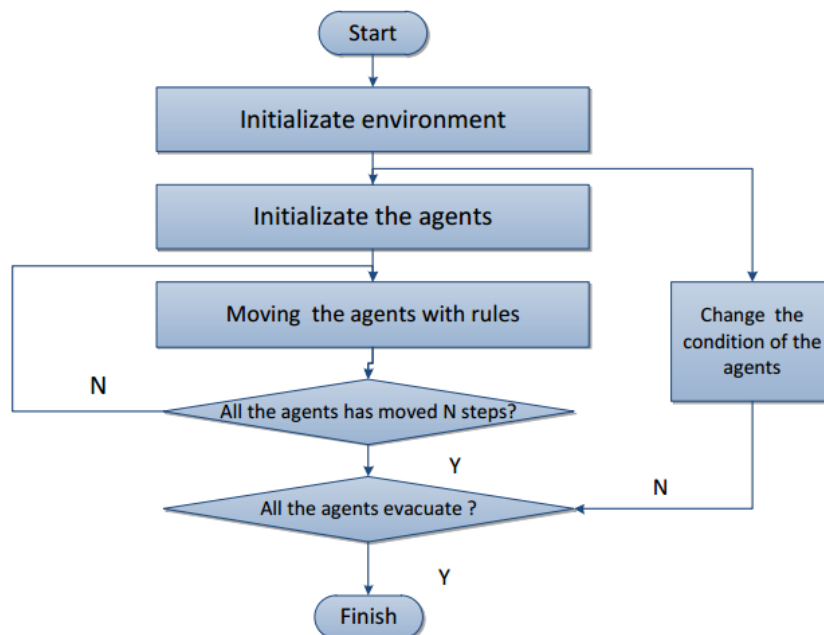


Figure 11 Simulation flow

5 The simulation realization

Based on the previous safety evacuation model, the software Net logo can be used to complete the simulation of the safe evacuation system.

NETLOGO

Netlogo is developed by the Centre for Connected Learning and computer-based Modelling.

It inherits the basic characteristics of the logo language, but also improves the logo language to control the defects of a single individual. It can simulate thousands of individuals in modelling. Therefore, Netlogo could use the agent based Modelling method. In fact, Netlogo is a set of Java libraries and it can be written in Java with object-oriented programming methods, Users can use these reusable class libraries to build models and simulate complex systems.

5.1 Simulation realization

The image below is a simulation interface for security evacuation based on Netlogo platform development. The simulation interface is composed of environment initialization, crowd initialization and different security evacuation strategy buttons and simulation visual window, monitoring output and other functional interfaces. In order to facilitate the observation of the simulation results, the speed of speed slider adjustment model is set up.

(1) Environmental initialization

The environment initializes the plane layout of the space structure and adds the fire point. Different colours represent different types of facilities and have different attributes.

(2) Crowd initialization

The crowd initialization mainly completed the random generation of people in the middle of the emergency. The generated agents were randomly scattered throughout the map, People of different colours represent different attributes and take different decisions to make different behaviours under safe evacuation. The slide “number” is set to control the number of people.

To simulating the real world ,agents will be die in the situation that they are given birth on the fire patch or they could not find a way to get out.

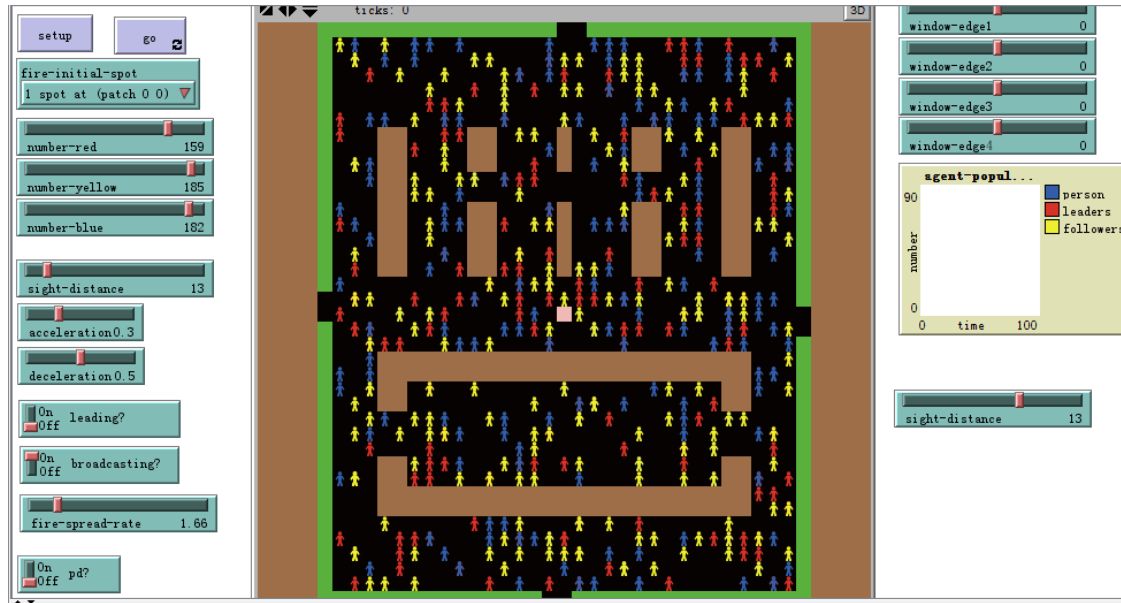


Figure 12 Crowd initialization

(3) Monitoring output

The monitoring output can realize the state analysis, grid attribute analysis and statistical data output of the simulation process. The monitoring feature enables the observer to view its property values for each turtle, including current coordinates, moving speed, moving direction, and moving targets. For each patch, you can view the properties of its physical facilities. The plot feature is used to estimate the current number of people who are not evacuated and the number of people who are attached to the crossing, so that they can evaluate the efficiency of the evacuation

Questions of the simulation

The problem that the simulation wants to solve is whether the coordinated agent can help or not? and the other problem is that what will happened if the fire is on the exits? Now the simulation of escaping without the coordinated agents, the simulation of escaping with the coordinated agents and the exits with the fire will be done and the results will be used to solve the problems.

5.2 Simulation results and analysis of self-escaping model

In this simulation environment, a certain number of evacuees were randomly generated, and three types agent groups were divided into three colours: red, blue and yellow.

Among them, the red crowd is a group of people who are familiar with the environment and have some knowledge and skills of emergency escape. The blue crowd represents the ordinary group, which may not choose to flee from path where are more people; but they not know much about the exits. The yellow crowd represents the following people, and it is very likely to follow large groups to escape during the evacuation and miss the way as a group.

In the simulation, each tick of the model will be updated with a plot. We can get the current number of people in different groups and the total number of stranded people,

while the number of people at different exits varies over time. The following is a 2D interface for randomly generated groups of 200 people in the environment, and the crowd is randomly distributed in various locations in the market.

There are the pictures which show the evacuation time of different crowds under the 10th simulations

Ticks for the evacuation											
	1	2	3	4	5	6	7	8	9	10	average
red group	77	68	78	70	77	71	70	71	75	79	73.6
blue group	82	79	79	75	85	87	83	79	86	84	81.9
yellow group	169	181	80	81	91	89	96	82	90	81	104
total	169	181	80	81	91	89	96	82	90	81	104
dean people	5	6	6	2	9	9	9	3	2	3	5.4

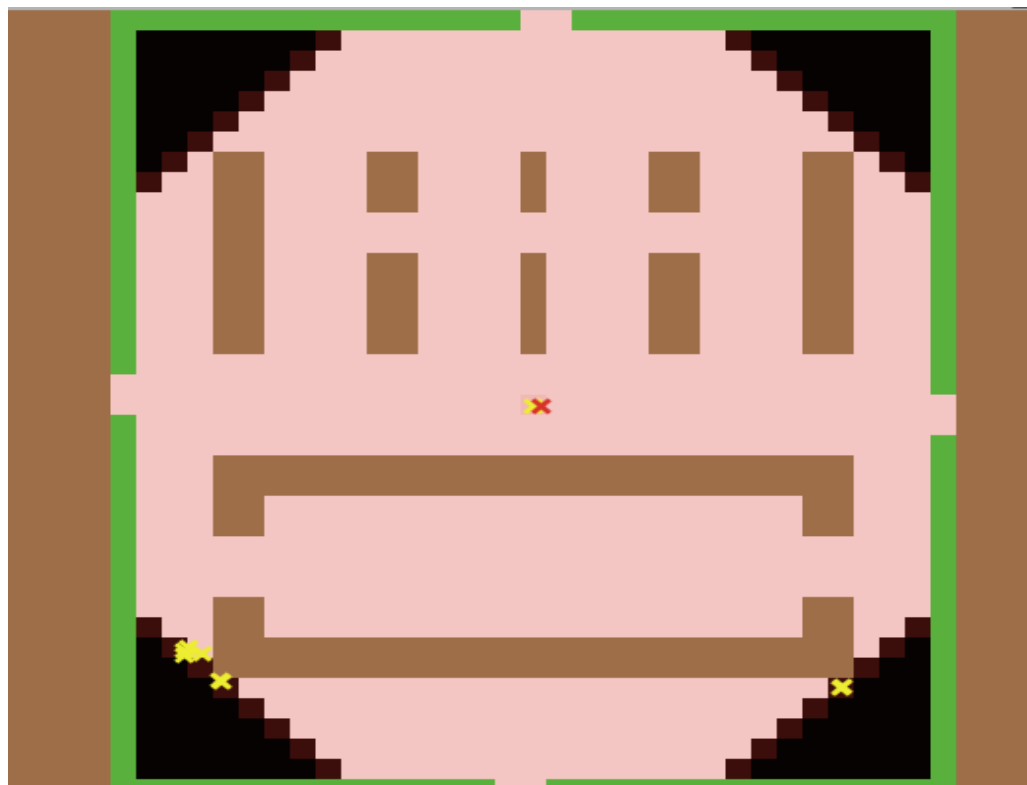


Figure 13 Ticks for the evacuation and the simulation situation

From the simulation situation, we found that some red agents and yellow agents dead when the fire start to burn, it is reasonable when considering about the gas fire situation. It is also visible that some of the yellow members dead because that they could not find the way to evacuate. Considering about most of the yellow one gather and go out of the fire smoothly, the algorithm for most yellow one is right and the simulation is successful. The result of this kind of simulation that some of the yellow one who like to gather or following may be could not find their way to evacuate also fits the real world.

From the chart above, we found that the red group usually only needs fewer time to get away from the fire situation. The escape efficiency of the yellow type, which follow the crowd in an emergency, is far less than the red and blue people. Blue agents is a little

slower than the red one, so gathering is dangerous for the crowd evacuation and the familiarity with the scene helps improve escape chances. Finally the crowds eventually escape time also become the "bottleneck" in the process of evacuation.

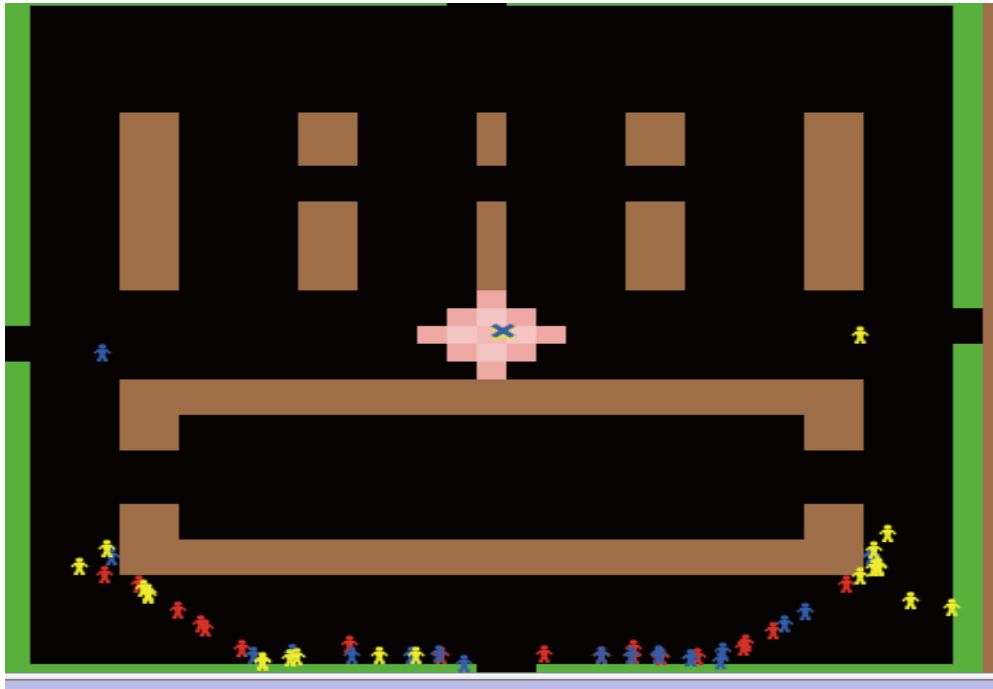


Figure 14 "Bottleneck" in the exits

However, most people just choose one or two exits to escape and do not want to leave once they found a exit to escape. Therefore, it is necessary to consider a strategy or method, make the whole evacuation in relatively evenly using four exits, this will be bound to greatly reduce the evacuation time, so as to improve the efficiency of the evacuation.

5.3 Simulation results and analysis of escaping with the coordinated model

In the coordinated escape strategy, we still maintain the Settings of red, blue, and yellow people who have escaped from our own escape. But we will set the red agents to communicate with other groups to choose a better exit., the yellow one will be the followers and the blue one have half of the chance to reject the suggest. We can show this coordination force through the reaction time, walking speed, and the selection of the path of the crowd. The following is the simulation of the evacuation of people based on the coordinated escape strategy.

There are the pictures which show the evacuation time of different crowds under the 10th simulations.

Ticks for the evacuation											
	1	2	3	4	5	6	7	8	9	10	average
red group	80	73	81	72	87	86	73	81	74	75	78.2
blue group	103	80	133	105	92	178	102	143	149	96	118.1
yellow group	84	87	76	75	82	79	88	81	74	80	80.6
total	103	80	133	105	92	178	102	143	149	96	118.1
dead people	0	0	0	0	0	0	0	0	0	0	0

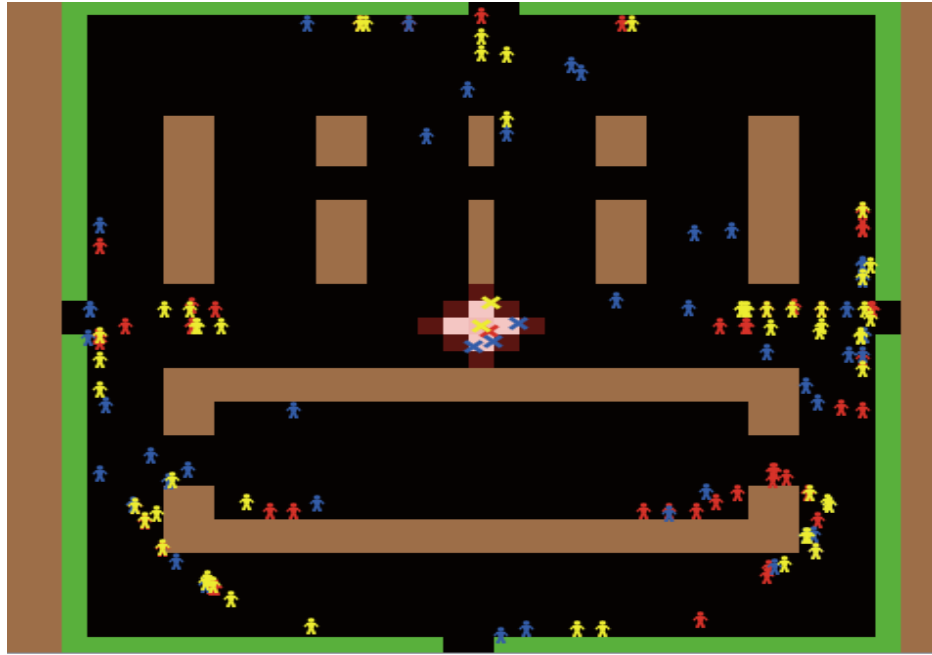


Figure 15 Ticks for the evacuation and the simulation situation

For the observation of the above simulation process and the analysis of the relevant chart statistical results, we found that the escape time of the red population was not significantly shorter than that of the previous ones. But with the red agents' coordination and guidance, the evacuation time of the yellow crowd is much shorter than before and there is no one dead after receiving the coordination form the red agents. However, the blue one takes more time than the first situation, because half of them reject the coordination. This results shows the importance of the coordinating agents. Once the agents receive the coordination the evacuation time will shorter almost half of it, while the agents reject the coordination they will take more time than they do it by themselves before in the way of evacuation. Compared with the escape strategy, the blue crowd and the yellow crowd dispersed to the four exits in order to evacuate, based on the coordinated escape strategy.

5.4 Simulation results and analysis of escaping with limit exits model

After the self-escape strategy and coordination strategy from the simulation and comparative analysis, there are also maintain the original red, blue and yellow groups

and still use the coordinated agents to guide the others. We assume that two exits are limited by the fire, so most people can only choose two other outlets to evacuate. Observing the simulation process under the restriction of export, we found that in the condition of two fired exits, people in the guiding of the red coordinator agents evacuate quick than the unguiding model, even they only have another two exits to use. It is also clear that the role of the red coordinator in the evacuation process is obvious.

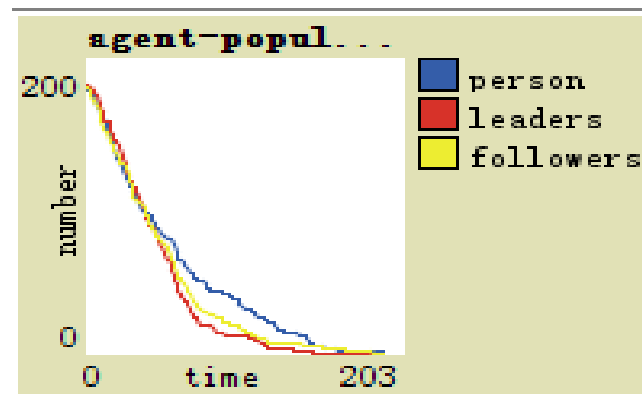


Figure 16 Limited exits curve with manager agent

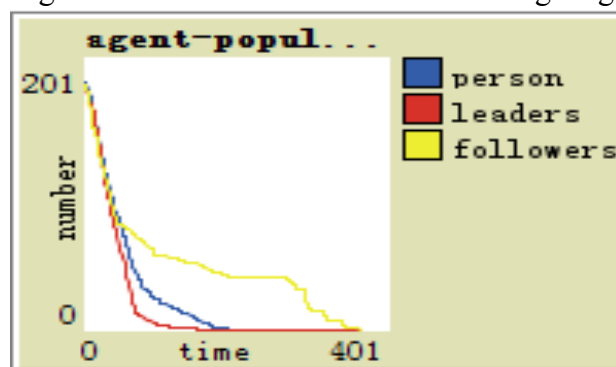


Figure 17 Limited exits curve without manager agent

5.5 Summary

In the previous simulation case, we first divided the crowd into red, blue and yellow ones, and then simulates the process of self-crowd evacuation. We also gave the red crowd a coordinated ability to upgrade the red ones into a coordinated crowd. The interaction between Agent in the MAS system is used to communicate and coordinate with other groups, other Agent groups, and a simulation of the escape process under the condition of population harmony is simulated. Finally, we designed the evacuation process for the crowd under restricted exits. Based on the previous simulation results and analysis, we draw the following conclusion: in the process of safe evacuation, the role of the coordinated crowd can indeed improve the evacuation effect. Comparing with the simulation process and statistics of the escape and coordinated escape, it can be found that both evacuation time and exit efficiency have been optimized and improved.

In the real world, the result of these two problems also give some ideas for the fire evacuation. In the previous simulation, we can see that the red crowd was familiar with the environment and had better survival skills. In various simulations, they were able to escape in the shortest possible time and help others escape. Therefore, some staffs must be trained for the company on large public occasions or some robots should take the role of the coordinated agents. As more and more people have mastered the art of escape, it is equivalent to the increasing number of red people in the simulation process. This improves the speed and efficiency of crowd evacuation and saves more people's life.

6 Conclusions & Future Work

The research work in this paper is mainly in the following aspects:

To summarize the representative research methods of previous researchers. discusses the behaviour models of people in macro and micro perspectives, analyses their (behaviour models) advantages and disadvantages, and expounds the simulation theory of crowd evacuation in detail. This research also quantifies the crowd behaviour information to simulation.

Explain the classification of crowd evacuation models and Agent based group modelling technology. Based on Agent interaction model, the basic characteristics of the population, the environment, the walking rules of pedestrians, the identification of obstacles, the direction of people's movement and the speed of people walking, it has established an evacuation model.

This article also introduced Netlogo simulation software. The crowd evacuation is simulated by using Netlogo simulation software. In the simulation process, the crowd is divided into different Agent groups according to the similarity of the individual in the evacuation group. FLOCKING and PSO algorithm are introduced in to describe the group relationships between the agents' groups. A kind of new coordinated agents are used in the paper and the results of the simulation shows that this kind of new agents could shorten the time of crowd evacuation.

Of course, there are some shortcomings of this article. The first one is that there is no more consideration of the effects of smoke and fire on people, the only consideration about the fire one is the diffusing. (even not the toxicant in the fire and whether the fire would wander or not). The second one is that the research on Agent group in the model is not deep enough. The interaction between groups cannot simulation the real one in the world. The MAS should be further studied and we should focus on the exchange of information and energy inside and outside the system to achieve better simulation results.

7 Reference

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Appendix 1 – Program Code(Edition of 5.3.1)

```
globals [  
  row  
  aisle  
  goal-x goal-y  
  shrink  
  shrink2  
  shrink3  
  shrink4  
  n  
  crowd-spots  
  fire-spots  
  
  escape  
  casualties  
]
```

```
patches-own [ fire floor? exit? f g h parent-patch ]
```

```
turtles-own[  
  destination  
  leader ; the leader which this turtle is following, can be nobody  
  speed  
  path  
]
```

```
to setup  
  ;; (for this model to work with NetLogo's new plotting features,  
  ;; __clear-all-and-reset-ticks should be replaced with clear-all at  
  ;; the beginning of your setup procedure and reset-ticks at the end  
  ;; of the procedure.)  
  __clear-all-and-reset-ticks  
  setup-patches  
  setup-turtles  
  set-default-shape turtles "person"  
  recolor-patches  
  if pd? [ask turtles [pd]]  
  reset-ticks
```

end

to setup-turtles

```
crt number-red [ set color red ]
crt number-blue [ set color blue ]
crt number-yellow [ set color yellow ]
ask turtles [
  set path []
  set leader nobody
  move-to one-of patches with [pcolor = black]
  set speed 1
]
```

end

to go

;stop condition

if all? turtles [pcolor = red] [stop]

ask turtles [

if broadcasting? [

; broadcast-crowd-spot

broadcast-fire-spot

]

if color = red [

if leading? [call-follow-me]

move-toward min-one-of available-exits [distance myself]

]

if color = blue [

ifelse any? patches with [exit? and distance myself < sight-distance]

[move-toward one-of patches with [exit? and distance myself < sight-distance]]

[

ifelse leader != nobody and leading? and any? turtles with [color = red and distance myself < 10]

[

move-toward leader

; face one-of turtles with [color = red and distance myself < 10]

; fd speed

]

[

; ifelse random 10 < 1

; [

```

        move-toward min-one-of available-exits [distance myself]
;      ]
;      [ move-to one-of neighbors with [floor? and fire = 0] ]
    ]
  ]
]

if color = yellow [
  ifelse any? patches with [exit? and distance myself < sight-distance]
  [ move-toward one-of patches with [exit? and distance myself < sight-distance] ]
  [
    ifelse leading?
    [
      let c crowd
      ifelse c != false
      [ move-toward min-one-of available-exits [distance c] ]
      [ move-to one-of neighbors with [floor? and fire = 0] ]
    ]
    [
      if any? turtles with [color = red or color = blue and distance myself < 2][
        face one-of turtles with [color = red or color = blue and distance myself
< 2]
        fd speed
      ]
    ]
  ]

;      move-toward min-one-of available-exits [distance myself]
;      ;[ set leading? false ]
    ]
  ]

  speed-adjust
  while [patch-ahead speed != nobody and not ([floor?] of patch-ahead speed) ][lt
random 90 rt random 90]
  fd speed
]

exit

fire-burning          ; this causes the "spreading" of heat
recolor-patches        ; colour patches according to heat

tick

```

```

do-plot
end

```

```

to fire-burning
  ask patches with [fire > 0 and fire < 100 ] [ set fire fire + fire-spread-rate ]
  ask patches with [fire >= 100] [ ask neighbors4 with [fire = 0][set fire fire + fire-
spread-rate] ]
  ask turtles with [fire > 10][set shape "x" stamp die]
end

```

```

to-report crowd
  let person-around turtles in-radius 5 with [fire = 0]
  if not any? person-around [report false]
  let des-x mean [xcor] of person-around
  let des-y mean [ycor] of person-around
  report patch des-x des-y
end

```

```

to-report available-exits
  report patches with [exit? and not member? self fire-spots]
end

```

```

to move-toward [target]
  ifelse distance target <= 2
  [ face target
  ;   fd speed
  ]
  [
  ;   if member? target fire-spots [ set path [] set target one-of available-exits ]
    if empty? path [
      set path min-route target
    ]
    ifelse not empty? path
    [ face first path
      if patch-here = first path [set path but-first path]
    ]
    [ face min-one-of neighbors with [floor?][fire]]
  ]
]

```

end

to speed-adjust

```
  ifelse (is-patch? patch-ahead (speed * 2)) and any? turtles-on patch-ahead speed
  [ stop ]
  [
    ifelse (is-patch? patch-ahead (speed * 2) and any? turtles-on patch-ahead (speed *
2))
    [ if speed > ([speed] of one-of turtles-on patch-ahead (speed * 2)) [
      set speed speed - deceleration ] ]
    [ set speed speed + acceleration ]
  ]
  if speed > 1 [set speed 1]
  if speed < 0 [set speed 0]
```

end

;to random-move

```
;  ifelse any? patches in-radius sight-distance with [exit? and not member? self fire-
spots]
;  [ move-toward min-one-of patches with [exit? and not member? self fire-
spots][distance myself] ]
;  [ let d one-of neighbors with [floor?] face d fd speed ]
;end
```

to call-follow-me

```
  ask other turtles in-radius sight-distance [
    if color = yellow [set leader myself]
    if color = blue and path = [] and random 10 < 5 [ set leader myself ]
  ]
```

end

to broadcast-fire-spot

```
  if any? patches in-radius sight-distance with [fire > 0][
    set fire-spots (patch-set fire-spots (patches in-radius sight-distance with [fire > 0]))
  ]
```

end

to exit ;directs turtles to exits after they leave theatres

```
  ask turtles with [exit?][set escape escape + 1 die]
```

end

```

to setup-patches
  set crowd-spots no-patches
  set fire-spots no-patches
  ask patches [ set floor? false set exit? false ]
  draw-concourse
  draw-walls
  ask patches with [pcolor = red][
    set exit? true set floor? true
    ask one-of neighbors with [pcolor = green][ set exit? true set floor? true ]
  ]
  ask patches with [ pcolor = black ][ set floor? true ]
  setup-fire
end

to draw-concourse
  ask patches with [pxcor >= -20 and pycor >= -19 and pxcor <= -17 and pycor <= 19]
  [ set pcolor brown]
  ask patches with [pxcor >= 17 and pycor >= -19 and pxcor <= 20 and pycor <= 19]
  [ set pcolor brown]

  ask patches with [pxcor >= -12 and pycor >= 3 and pxcor <= -11 and pycor <= 12]
  [ set pcolor brown]
  ask patches with [pxcor >= 5 and pycor >= 10 and pxcor <= 6 and pycor <= 12]
  [ set pcolor brown]
  ask patches with [pxcor >= 11 and pycor >= 3 and pxcor <= 12 and pycor <= 12]
  [set pcolor brown]
  ask patches with [pxcor >= -6 and pycor >= 10 and pxcor <= -5 and pycor <= 12]
  [set pcolor brown]
  ask patches with [pxcor >= 0 and pycor >= 10 and pxcor <= 0 and pycor <= 12]
  [set pcolor brown]
  ask patches with [pxcor >= -6 and pycor >= 3 and pxcor <= -5 and pycor <= 7]
  [set pcolor brown]
  ask patches with [pxcor >= 0 and pycor >= 3 and pxcor <= 0 and pycor <= 7]
  [set pcolor brown]
  ask patches with [pxcor >= 5 and pycor >= 3 and pxcor <= 6 and pycor <= 7]
  [set pcolor brown]

  ask patches with [pxcor >= -12 and pycor >= -6 and pxcor <= -11 and pycor <= -3]
  [set pcolor brown]
  ask patches with [pxcor >= -10 and pycor >= -4 and pxcor <= 10 and pycor <= -
3]
  [set pcolor brown]
  ask patches with [pxcor >= 11 and pycor >= -6 and pxcor <= 12 and pycor <= -3]
  [set pcolor brown]

```

```

ask patches with [pxcor >= -12 and pycor >= -13 and pxcor <= -11 and pycor <= -
10]
[set pcolor brown]
ask patches with [pxcor >= -10 and pycor >= -13 and pxcor <= 10 and pycor <=
-12]
[set pcolor brown]
ask patches with [pxcor >= 11 and pycor >= -13 and pxcor <= 12 and pycor <= -
10]
[set pcolor brown]
end

```

to draw-walls

```
;; don't let the window be bigger than the right chamber
```

```

ask patches with [ pxcor = -16 ][ set pcolor green ]
ask patches with [ pxcor = -16 and pycor = window-edge1 ][ set pcolor red set exit?
true]

```

```

ask patches with [ pxcor = 16 ] [ set pcolor green ]
ask patches with [ pxcor = 16 and pycor = window-edge2 ][ set pcolor red set exit?
true]

```

```
;; ... draws left edge in red
```

```

ask patches with [ pxcor >= -16 and pxcor <= 16 and pycor = -19 ][ set pcolor green ]
ask patches with [ pxcor >= -16 and pxcor <= 16 and pycor = -19
and pxcor = window-edge3 ][ set pcolor red set exit? true]

```

```

ask patches with [ pxcor >= -16 and pxcor <= 16 and pycor = 19 ][ set pcolor green ]
ask patches with [ pxcor >= -16 and pxcor <= 16 and pycor = 19
and pxcor = window-edge3 ][ set pcolor red set exit? true]

```

```
;; make sure no turtles are embedded in the middle wall
```

```
;; if the window size changed
```

end

to setup-fire

```

if fire-initial-spot = "1 spot at (patch 0 0)" [ ask patch 0 0 [set fire 100] ]
if fire-initial-spot = "2 spot at (patch -16 0) and (patch 16 0)" [
ask (patch-set (patch -16 0) (patch 16 0) (patch -16 1)(patch 16 1) (patch 16 -
1)(patch -16 -1)) [set fire 100 ]
]
end

```

```

to do-plot
  set-current-plot "agent-populations"
  set-current-plot-pen "person"
  plot count turtles with [color = blue]
  set-current-plot-pen "leaders"
  plot count turtles with [color = red]
  set-current-plot-pen "followers"
  plot count turtles with [color = yellow]
end

to recolor-patches ;; color patches according to heat
  ask patches with [ floor? ] [ set pcolor scale-color red fire 0 120 ]
end

to-report min-route [des]
  if is-turtle? des [set des [patch-here] of des]
  if [fire] of des > 0 [set des min-one-of available-exits [fire + distance des] ]
  if distance des > sight-distance [ set des min-one-of patches in-radius 5 with [floor?]
[distance des] ]
  let source-node patch-here
  let search-done? false
  let search-path [ ]
  let current-node 0
  let open [ ]
  let closed [ ]
  ; add source patch in the open list
  set open lput source-node open
  ; loop until we reach the destination or the open list becomes empty
  while [ search-done? != true ]
  [
    ifelse length open != 0
    [
      set open sort-by [ [f] of ?1 < [f] of ?2 ] open
      set current-node first open
      set open but-first open
      set closed lput current-node closed
      ask current-node
      [
        ifelse any? neighbors with [self = des]
        [ set search-done? true ]
        [
          ask neighbors with [ floor? and (not member? self closed) and (self !=
parent-patch) and fire = 0]

```

```

    [
      if not member? self open and self != source-node and self != des
      [
        set open lput self open
        set parent-patch current-node
        set g [g] of parent-patch + 1
        set h distance des
        set f (g + h)
      ]
    ]
  ]
]
[ report [ ] ]
]
set search-path lput current-node search-path
let temp first search-path
while [ temp != source-node ]
[
  set search-path lput [parent-patch] of temp search-path
  set temp [parent-patch] of temp
]
;set search-path fput des search-path
report reverse search-path
end

```