Simulating Rescue of Agents in Crowds during Emergency Situations

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***Abstract*—The area of crowd simulation has been shown to be challenging due to the complexity of human behavior. In this paper, we present a novel approach for the loading of dependent agents by altruists in exit situations, to be applied in games and simulations. With this model is possible to identify how many altruists agents are needed to carry a dependent one, as well as to predict the distance that they can be carried. In addition, we demonstrate that there is a relationship between NIOSH equation and the maximum weight that people can carry. We applied our method in some case studies containing 60 simulations. In this article we present the created approach, as well as some performed tests, comparing two different strategies for group rescuing.**

***Keywords*-Crowd simulation, rescue method, injured people motion**

I. Introduction

Several studies have been conducted in past years to reproduce the human behavior in virtual worlds [1] [2] [3] [4] [5]. Those researches allow to simulate in a convincing way the movement and many actions of virtual humans in games, crowd simulation and movies. Realistic behavior is important in simulations of emergency and panic situations, so the comfort levels and the security of people can be estimated into buildings and large public places.

Data collected from those simulations help security engineers to investigate how to minimize the effects of panic situations and how to facilitate the evacuation and rescue of injured people [6] [7]. Despite many human behaviors and actions that have been described in crowd simulation models, to reproduce some actions remains as a challenge to scientific community. For instance, several evacuation simulations have been created to model the escape of agents from specific spaces, but none describe methods to simulate helper agents carrying dependent and injured ones to exit doors.

This paper presents a new approach to simulate altruist groups carrying injured agents to escape from an environment during a hazardous situation. The proposed model is based on late research on ergonomic field of past decades [8] [9] [10], which identified the main characteristics that influence ability of people to carry weight. Our method provides agents with different abilities to carry others, and dependent agents that need to be carried by one or more agents in a rescue model. As result, helper agents can carry others and walk for a time before the exhaustion. In this case, they can give up the dependent agents to save herself/himself. In addition, we also simulate the group collaboration in order to improve the efficiency to rescue dependent agents. The main application is the possibility to simulate a hybrid population, i.e. having helpers and dependents, and to estimate the simulation times and number of rescued people. Although, our model can be expanded and employed to carry any other object, i.e. stretchers, boxes or rescue equipment, we focused on rescuing agents in this work.

In the next sections, we present related works, followed by the proposed model. After that, we discuss the main results, conclusions and future works.

II. Related works

In this section we summarize works from three specific domains: crowd simulation, agents interaction and ergonomic studies.

Crowd simulation has received attention of many research groups around the world in last years, mainly to predict the crowds dynamics. For that purpose, simulation models are required to define good strategies of escaping and rescuing injured agents.

Among the most prominent works in crowd simulation, [1] compiled a list of main behaviors of people motion in panic situations. Those behaviors have been described into socio-psychological literature [11], [12], [13] [14] and has been used to validate the level of realism of new models of crowd simulation. Below we present some of these characteristics:

- People start to move faster than normal;
- Each individual starts to push, so the movement become more physical;
- There is an arc formation at exits;
- Corridors become jammed and pressure increases to dangerous levels;
- People replicates neighbors behaviors; and
- Many alternative exits are neglected.

Besides that, [1] proposed a simulation model based on social and physical forces, allowing to replicate several

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behaviors from this list. In this work, some case studies were conducted to simulate the escape situations when visibility is low. In those scenarios, each agent has been defined with a personal individualism level. So, agents with low level of individualism appear to follow others agents to escape from emergency situations.

Helbing's model has been extended by [15], so each agent is endowed with altruism and dependency level. During a rescue situation, agents with high level of dependency started to move in same speed of altruist's agents, as they are from the same family.

In terms of interaction among agents, researches have focused on providing the animation and interaction of multiple characters. In [16], the authors propose to model agents interaction by combining motion capture data so, in an offline preprocessing, the motion is analyzed, control parameters are optimized and pendulum trajectories are generated to represent the relationship between two characters. Those data are used into synthesis step, so the physical interaction is added to the pendulum trajectories creating a reactive movement in real time. Chan [17] combined two interaction motions by detecting the type of interaction contained in the inputs and redefining the timing for the interaction composition. Whereas, Shum [18] synthesizes animations of multiple characters by evaluating competition and collaboration of interactions. The generated scores can be used to recreate animations of dense character interactions.

From the point of view of ergonomic research, Waters [19] reviewed an equation developed by the National Institute of Occupational Safety and Health (NIOSH), that identifies the risk level to human health when objects are lifted. The revised NIOSH equation allows to estimate the weight limit to the carrying/lifting task [19]. At first, NIOSH equation was utilized only for specific lifting tasks, but with the Waters's revision, many others characteristics present in tasks of lifting were considered. So, the equation can evaluate the risks to emerge injuries in the back, the knees and the joints.

For that, biomechanical, physiological and psychophysical factors were considered in the modelling of the equation. From the point of view of the biomechanical factor, the criterion used was the limit of the compression force of the cervical disks (approximately 3.4 kN), whereas for the physiological factor the criterion used was the maximum energy expended in weight lifting (between 2.2 and 4.7 kcal / min). However, the physiological factor has the highest acceptable weight (75 % for women and 99 % for men).

The revised version of the NIOSH equation [19] allows the definition of an index (Equation 1), where values between 0 and 1 indicates that the risk for weight lifting is limited. Values between 1 and 3 indicate a moderate risk, while above 3 indicate a high risk of injury.

$$niosh = \frac{Weight_L}{Weight_R}, \quad (1)$$

where $Weight_L$ is the weight lifted by a person, $Weight_R$ is the maximum recommended weight to be lifted, which can estimated by the following equation:

$$Weight_R = LC \times HM \times VM \times DM \times AM \times FM, \quad (2)$$

where LC defines a load constant, that is, around 1/3 of the person's weight, HM is calculated by $HM = 25/H$, so that H is the horizontal distance in centimeters between the person's center and the load object. Also, it's important to note that with the increase of such distance, the compression force applied to the cervical spine discs increases too, reducing the weight limit that a person can carry. The height factor VM is defined by the equation $VM = 1 - 0.003(V - 75)$, where V is the height of the person's hands that are holding the object. The vertical displacement factor DM is defined by the equation $DM = 0.82 + 4.5\Delta$, where Δ defines how much the object has been lifted. The frequency factor AM is defined by means of a table, with value 0.91 for a single lifting. Similarly, the FM handle factor is defined by means of a table, and for good grip conditions the value 1 is used.

Another study in the area of ergonomic is the research carried out by Snook [20], in which the ability of men and women to carry different weights over short distances (2.5m, 5m and 10 meters) was investigated. The empiric data was organized into tables and allows to identify the percentage of people who can carry a certain weight. Table I and II present the percentage of men and women who can carry different weights by 10 meters of distance.

Table I
PERCENTAGE OF WOMEN WHO CAN CARRY LOADS OF 14, 18, 23, 27 AND 30 KG OVER 10 METERS. SOURCE: SNOOK [20].

WOMEN	
Lifted weight (Kg)	Percentage that can carry the load
30	0%
27	13%
23	39%
18	81%
14	100%

Regarding the ability to load an object, [8] listed the main characteristics that impact a person's ability to lift an object. Among them, the person's age, muscular strength, aerobic power, anaerobic power, physical composition, gender, load size, load location, biomechanical factors, nature of the terrain (grass , Sand, floor, etc.), terrain slope, weather effects (e.g. snow depth) and protective clothing are examples.

Although the many existing works in crowd simulation investigate group formation and some of them explore the issue of evacuation, it remains a challenge to simulate an emergency situation in which injured or disabled agents are loaded to the nearest exit. For instance, the works of in [21], [22], [23] uses a least effort cellular automata

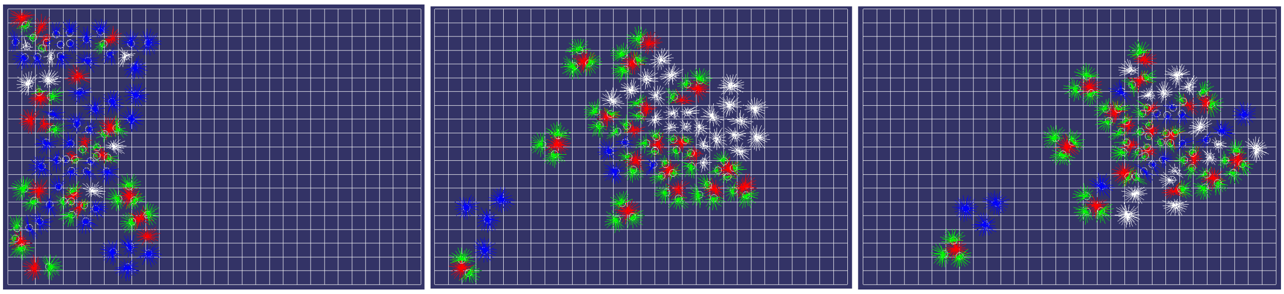

Figure 1. Rescue simulation with 100 agents (20 dependents and 80 altruists).

Table II
PERCENTAGE OF MEN WHO CAN CARRY LOADS OF 20, 24, 33 E 45 KG OVER 10 METERS. SOURCE: SNOOK [20].

MEN	
Lifted weight (Kg)	Percentage that can carry the load
45	22%
33	58%
24	83%
20	89%

to simulate pedestrian crowds in evacuation scenarios, so the motions and goals of agents are probabilistic. On the other hand, Helbing [1] and SAFEgress (Social Agent For Egress) [24] use force-based models approach to simulate evacuation of pedestrians. Therefore, the present work proposes to adapt the biologically inspired simulation model of BioCrowds [25], so that agents can collaborate to load another agent and leave the environment. In fact, any other crowd simulator could be used for collision avoidance, i.e. there is no dependence of BioCrowds [25] and our method.

III. PROPOSED MODEL

As illustrated in columns 1 and 2 in Table III, Snook [20] shows the percentage of population that can carry different weights for short distances, separating the results in groups of men and women. In the present model we assume that there is a correlation between the percentages of the population and the NIOSH index (column 3 in Table III). Moreover, when calculating the NIOSH value for the average population of men and women in Snook's work [20], we noticed that there is a linear relationship in the variation of the calculated NIOSH index and in the percentage of people who can carry.

In Table III, the percentage of women who can carry different weights and the value of the NIOSH index can be observed. Thus it can be seen that 100 % of women can carry 14 kg by 10 meters, with the corresponding NIOSH index being 1, that is, upper limit for low risk. On the other hand, when you have a woman loading 30Kg in weight, the calculated NIOSH coefficient is around 2.

When analyzing Snook data [20] for the percentage of men carrying weights by 10 meters, we can see that all men can carry 20 kg, while only 22 % can carry 45 kg (see Table IV). It should be emphasized that the tables presented in [20] do not show the load that no man can carry. Thus, when estimating the NIOSH index to 20Kg, we have a value of 0.95, that is, a result very close to the upper limit for moderate risk. For the 45Kg value, the NIOSH coefficient was calculated with the value 2.

Table III
ESTIMATED NIOSH INDEX FOR SNOOK EXPERIMENTS.

WOMEN		
Lifted weight (Kg)	Percentage that can carry the load	Estimated NIOSH
30	0%	2
27	13%	1.8
23	39%	1.6
18	81%	1.2
14	100%	1

Table IV
ESTIMATED NIOSH INDEX FOR SNOOK EXPERIMENTS.

MEN		
Lifted weight (Kg)	Percentage that can carry the load	Estimated NIOSH
45	22%	2
33	58%	1.5
24	83%	1.1
20	89%	0.95

Considering that the NIOSH index takes into account the characteristics of the person (such as height and weight) and how the load is lifted, this paper proposes the use of the NIOSH index to identify whether or not an altruistic person will be able to carry a person who needs help. To do so, we use the following assumptions:

Definition 1: Every agent has their own personal NIOSH index, where the index value ranges from 1 to 2, for women and from 1 to 2.3 for men.

It is observed that the men's index has the estimated value proportional to the one calculated in Snook's research [20]. This assumption was made in order to simplify the model, and to supplement the missing information on the weight that no man could carry. One of the reasons for these simplifications is the fact that we assume there is a linear relationship between the NIOSH index and the percentage of men who can carry weight for 10 meters.

Definition 2: An agent i will be able to lift an agent which weight is c, if the NIOSH index for that load is lower than the personal NIOSH index, as Equation 3.

$$niosh_c < niosh_i. \tag{3}$$

Definition 3: As an agent i carries a weight c, the NIOSH$_i$ index will decrease along the traveled distance, as in Equation 4:

$$niosh_i(s) = niosh_i(s-1) - 0.02||v_i(s)||, \tag{4}$$

where $v_i(s)$ is the velocity of agent i at instant s.

In the Equation 4, one can observe that the personal NIOSH index decreases with a factor of 0.02 per meter. This constant was computed based on the decay rate of the NIOSH index generated by data described by Snook [20]. In Figure 2 illustrates the decay as a function of traveled distance presented in the percentage of women who can carry 30 kg, 27 kg and 23 kg.

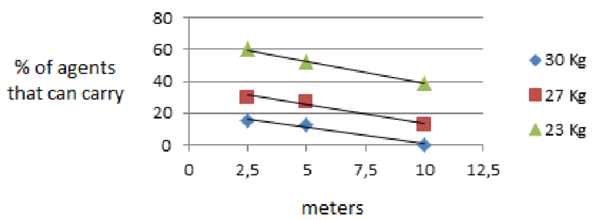

Figure 2. Percentage of women who can carry 30, 27 and 23 kg along 2.5, 5.0 and 10.0 meters.

Definition 4: Every agent i has a weight, a ray of perception, a level of altruism, and a level of dependency.

Each agent in the simulation model should receive a weight value, which will influence its ability to load other agents, this is based on the fact that 90% of agent weight is composed by the lean mass. So the weight is proportional to the force of agent. In addition, a ray of awareness to be able to identify agents who need help. Also, agents have levels of altruism and dependence that will define whether the agent will be helping or receiving help.

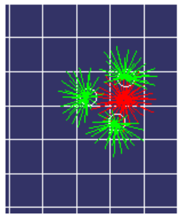

Figure 3. Group formation with 3 altruists and 1 dependent agent.

Definition 5: For a group of size n to be able to carry a dependent agent, the condition presented in Equation 5 must be satisfied:

$$\frac{p_d}{\sum_{i=0}^{n} c_i \times niosh_i(s)} < 1, \tag{5}$$

where p_d identifies the weight of the dependent to be loaded, while c_i is a recommended load for each altruist i of the group, the personnel NIOSH index in the time s.

Definition 6: Altruistic agents may be in one of the following states:

- REACHING: when the agent is going to meet the dependent agent;
- CARRYING: when the agent is carrying another agent to the exit; and
- LEAVING: when the agent is leaving the environment without loading other agents.

In Figure 3, it's present the a group formation with 3 altruists agents carrying a dependent agent. The altruists agents self organize around the dependent one.

Definition 7: Each dependent agent has its own group, which can be composed of a list of agents that are in the REACHING state and another list of agents in the CARRYING state.

In the simulations discussed in this work, it was decided to limit the size of the group in 4 agents. This value has been chosen in order to maximize the FM handle factor of the NIOSH index, so each agent can carry others holding one arm or one leg.

At each instant of time, the method verifies if an altruistic agent i in the LEAVING state can help to carry any dependent agent j from the simulation. If i can help j, it will be included to group of j, so agent i will be added to the list of agents in the REACHING state. As soon as i reaches the group of j (close enough to the dependent agent), i state changes to CARRYING, being removed from the list of REACHING agents.

Definition 8: The weaker agent in the group will not hamper one agent from be rescued.

Whenever a group is complete with 4 members, and they can not load the dependent, the altruistic agent with the lowest $niosh_i$ will be removed from the group. So, it will go from CARRYING state to LEAVING state and will no longer try to help carrying that dependent agent.

The specified definitions and main execution's flow to each agent step has been resumed into a single flowchart presented in Figure 4. At each step, the agent can be in one of possible states: LEAVING, CARRYING or REACHING. If the state is leaving, he will look for dependent agents. As soon as he find one, he will become candidate to be part of group that will carry the dependent agent (Definition 7). This is accomplished by including the altruist into list of REACHING agents. In case he didn't find any agent, he will keeping moving to the exit.

Those agents that already joined a group can be in state REACHING or CARRYING. While the altruist agent not get close to dependent one, he will stay in REACHING state and move toward the group location. As soon he reaches the group location, his state will be changed to CARRYING. As long as he keep carrying, his NIOSH index will be update. To do that, Equation 4 should be applied. In case the group cant carry dependent agent (condition presented in Equation 5), the weaker agent should leave the group (Definition 8).

Next section describes some obtained results with the proposed methodology.

IV. Results

We performed 60 simulations to evaluate the propose method in an environment of 30 meters by 20 meters of area. The agents are distributed in the environment on the left side of the environment (left image of Figure 1, and the exit is on the opposite side as pointed out in Figure 5. In the middle image of Figure 1, it is presented 100 agents leaving this environment. Some agents have been organized themselves in group to carry other agents. This cant be observed by green agents around red ones. Agents in state REACHING are presented in blue, while those in state LEAVING are presented white.

In Figure 6, it can be observed altruistic agents (displayed in green or in white) assisting dependent agents (displayed in red) to leave the environment. The green agents are those who are altruistic and are in the CARRYING state. White agents are altruistic and in the LEAVING state. One can observe the emergent formation of groups in Figure 6. People are uniformly organized around the dependent agent. It happens in BioCrowds [25] due to the method for competition for space that determines agents position close to their goal but avoiding occupying regions. Consequently, we can see red agents surrounded by the helpers, being that dependent agents is the goal position of altruists agents. On the other hand, some altruists agents can be stucked in environment trying to help dependent agents. This can be observed in the two agents in bottom left of Figure 6.

We used two strategies, in our simulations, to decide which dependent agent j each altruistic agent i should try to help. The first strategy used was to pick up the dependent agent j which is closer to agent i, since it can be "seen" by i. We implemented the perception radius as the "field of vision of altruistic agents", in the case of this result, we used 30 meters. Important to notice that in the case of this environment, all agents could be perceived by any other. Figure 7 shows the number of agents that were able to leave the environment with simulations of 50, 100, 150 and 200 agents, considering such strategy. In addition, we simulated varied percentages of dependent agents (20%, 40%, 60%, 65% and 70%) for each amount of agents. It is interesting to see that from 60% to 100% of dependent agents in the simulation, the situation is stable critical, meaning that almost all agents (from 90% to 100% were not able to leave the environment).

The second strategy used consists of an agent i choosing the group with less need for help, i.e. the altruist agent i should try to minimize the value of Equation 6, that is applied to each group. The agent i should prefer the group with the lowest missing load, maximizing the rescue chance. The Figure 9 shows the result of simulations with this strategy for different sizes of groups and percentages of altruistic and dependent agents.

$$p_d - \sum_{i=0}^{n} c_i \times niosh_i(s), \tag{6}$$

where p_d identifies the weight of the dependent to be loaded, while c_i is a recommended load for each altruist i of the group, $nisoh_i(s)$ is the personnel NIOSH index of agent i in the time s.

We compute the mean percentage of agents that successfully left the environment in both strategies. In Figure 9, we compared the results for both strategies, so we can conclude that the lower weight strategy allows a more efficient evacuation of environment. In addition, we can notice that the proportion of 60% of dependent agents is a critical point, where efficiency in rescue decreases drastically for both strategies of group formation.

As seen in Figure 10, has been observed in our simulations the formation of arcs close to exits. Although, this was an emergent behavior of crowd model, the present model of group formation and carrying ability appear to not affect this desired effect.

V. Conclusions and Future work

The present paper describes a method to simulate crowds, where agents can be rescued by others. We called the agents able to rescue as altruistic while the dependent ones are the agents that need help. We used works from literature in order to provide scientific basis for our algorithm that should simulate time, distance and load that agents could carry on. In addition, based on our results, we can predict how many agents should be in charge of rescue others during

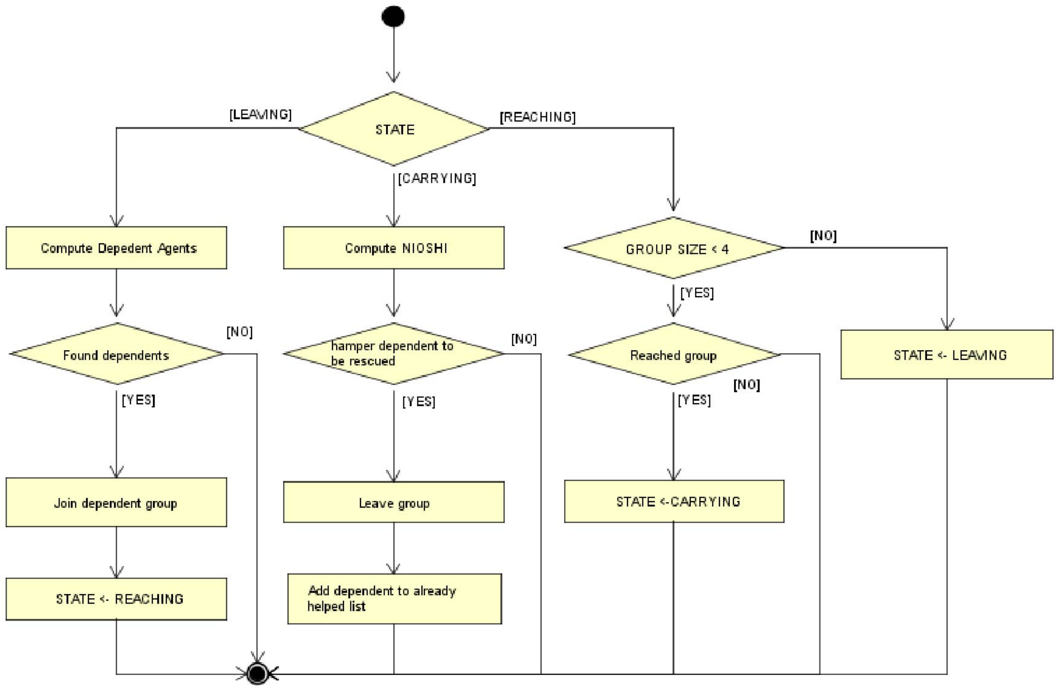

Figure 4. Flowchart of update execution.

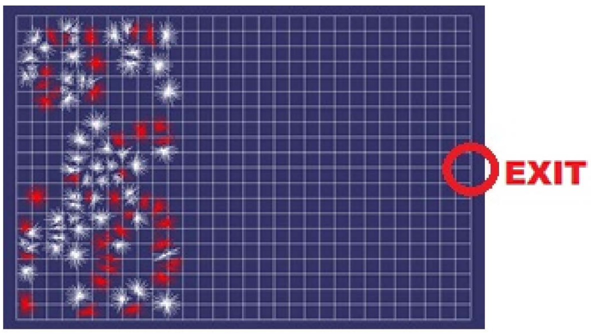

Figure 5. Simulation environment used in experiments.

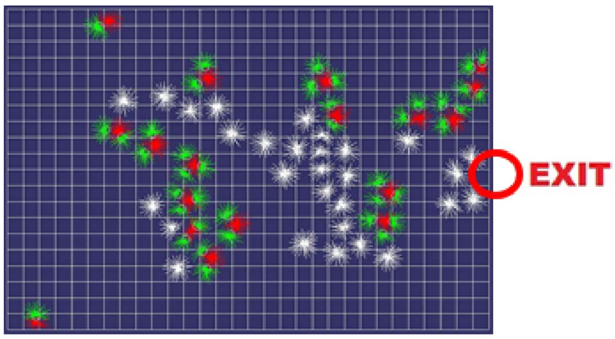

Figure 6. Altruist agents in green carrying dependents agents in red. Agents highlighted in white are leaving the environment without helping dependent agents.

hazardous situations. It can be noted that the result obtained indicates a linear relationship between the percentage of agents that can leave the environment and the percentage of dependent agents. This is correct till the proportion of 60 % of dependents and 40 % of altruists. After that, the simulations indicate that the situation is very critical and should be better investigated.

As future work, we intend to expand the model to treat more Physical attributes of the simulated agents, e.g. how the load capacity is impacted by an overweight agent.

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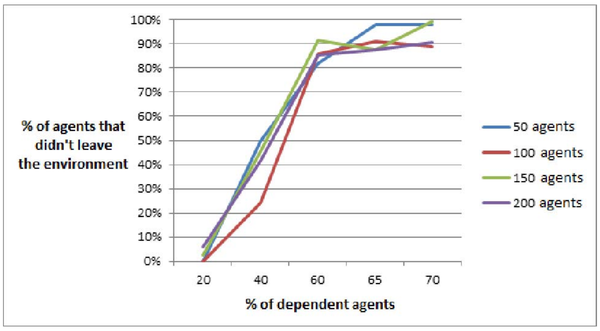

Figure 7. Percentage of agents that have managed to leave the environment for a *shorter distance* strategy.

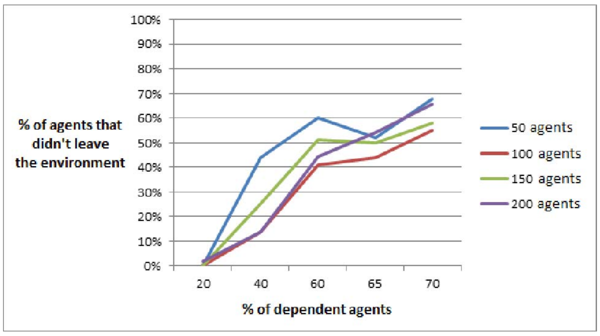

Figure 8. Percentage of agents that were able to leave the environment using a *lower weight* strategy.

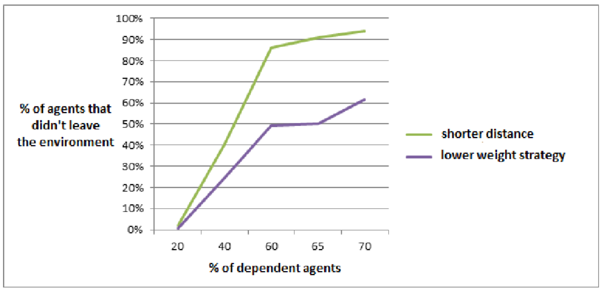

Figure 9. Comparison between the two rescue strategies.

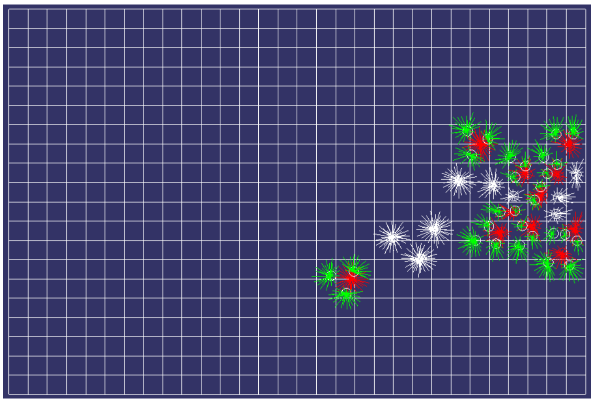

Figure 10. Starting the arc formation close to exits.

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