Crowd interactions in evacuations: an Evolutionary Game Theory approach

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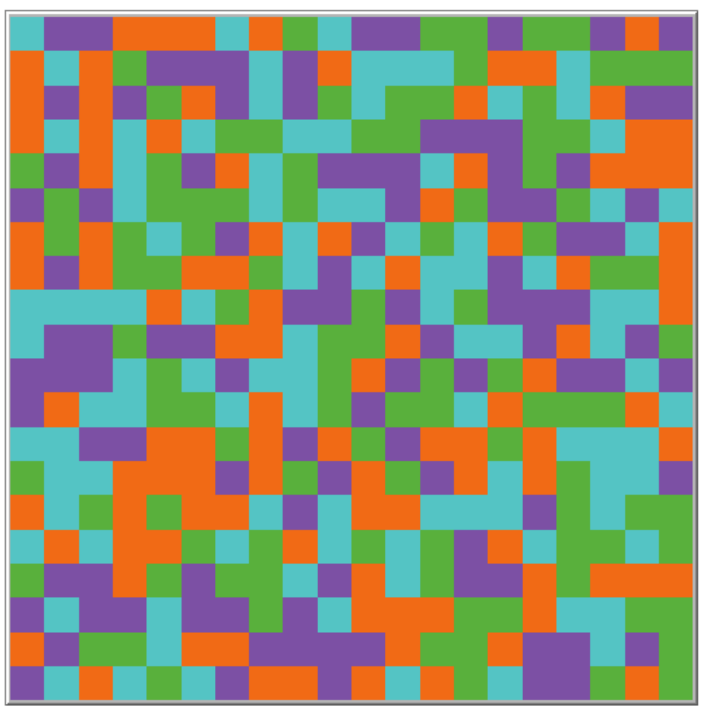
Abstract. The interactions between people in a crowd can be modeled as an agent-based game. Evolutionary Game Theory (EGT) approaches can be applied to different kinds of games to simulate the evolution of a system. I propose a trivial agent-based model to study crowd evacuations during some kind of emergency. I focus on the interactions between people in an emergency scenario. The results obtained suggest that this simple model can be useful to study the effectiveness of different safety measures.

Keywords: Evolutionary Game Theory · Game Theory · Evacuation.



1 Introduction

Evacuation protocols are one of the major factors capable of reducing the number of casualties during heartquakes, fires and other safety hazards. In very crowded environments there are some difficulties that prevent the successful outcome of these protocols. For example, in places like schools, stampedes are very common and, in general, the result of the evacuation heavily depends on the behaviour of the single individuals or groups of them. For this reason, studies on crowd behaviour in disaster emergency evacuations are a very promising technique to improve their execution and prevent casualties [1].

In this paper, I build an agent-based simulation, using NetLogo, to provide a better understanding of the evacuation environment and describe what kind of strategies should be undertaken to reduce the total evacuation time. In particular I focus on the interactions between the individuals involved in the emergency.

I choose to tackle this task with a game theoretical approach. The objective of this work is to model different behaviours in an evolutionary game with the objective of reducing the evacuation time. I also search for the specific parameters that help the game evolve to the desired stability. The ultimate goal of this study is to provide some insights on which factors contribute to an orderly and efficient evacuation.

2 The Game

The implemented game is defined by the different behaviours individuals engage in, during an evacuation. The particular setting being modeled is that of a situation in which people are trying to exit the building and, therefore, there is a queue which has been formed in front of the exit. In general, people tend to act in two different ways during an emergency: calm or impulsive.

Calm individuals are those who follow the rules of the evacuation plan and, when leaving the building, queue behind the people who precede them. Impulsive individual, on the other hand, tend to act in a more aggressive way, by trying to cut in line and in general, not following the instructions given [2].

It is clear that, for the evacuation to be successful, it is preferable, for the population, to be composed mainly of calm individuals. This because, calm individuals, tend to follow the instructions and do not cause stampedes and other dangerous phenomenons common in these situations.

There is a third type of individual that is taken in consideration for this game: the supervisor. In an evacuation, the supervisor has a central role as it is the person whose role is to control the correct progress of the plan. Their task is to prevent impulsive behaviours from other individuals and block those who try to cut in line or provoke stampedes [2].

At every time step, every individual interacts with another one and receives a payoff. The payoff matrix associated to this particular game is defined as:

Table 1. Payoff matrix for the evacuation game

	Calm	Impulsive	Supervisor
Calm	1	0	2
Impulsive	2	-1	0

Note that supervisors do not receive a payoff because they are not proper agents. Indeed, they do not change their strategy as we assume that they have received some training that prevent them to change their behavior. Moreover, other players can not become supervisors because they lack the necessary training.

If a calm person plays with another calm person, the two keep their place in the evacuation queue and both get one step closer to the exit. On the other hand, if a calm person plays with an impulsive person, they get their place in the queue stolen and does not get closer to getting out of the building. The impulsive person, instead, cuts in line and gets much closer to the exit. In the case of a game between two impulsive persons, the two fight and might hurt themselves, getting further from evacuating the building.

When calm persons play with supervisors, their payoff is very high as the supervisors reward their careful behaviour and help make their evacuation faster. When an impulsive person plays with a supervisor, instead, its attempt to cut in line is blocked.

At each time step, every player plays with another one, getting the corresponding payoff from the payoff matrix. Then, with some probability, they choose a random player and, if the payoff of the chosen player is higher than theirs, they change their strategy to that of the other one.

3 Basic Model

The model created in NetLogo uses the patches of the simulation world as the individuals. Every patch has an associated strategy and payoff.

In the simulation, the orange patches represent calm players, green patches are impulsive players and blue players are supervisors. For the experiments I used a population of 400 players.

From the definition of the model, I expected to see a decreasing trend for the number of impulsive people due to the presence of supervisors. The ideal scenario is the one where impulsive people disappear completely, leaving only calm people to perform the evacuation. But, if supervisors are not enough, impulsive players may take advantage of calm players and spread.

The first experiments performed with this model show what we expected. The supervisors have a positive effect on the outcome of the evacuation by favoring the increase in the number of calm people. The probability of revision does not affect much the general trend of the model.

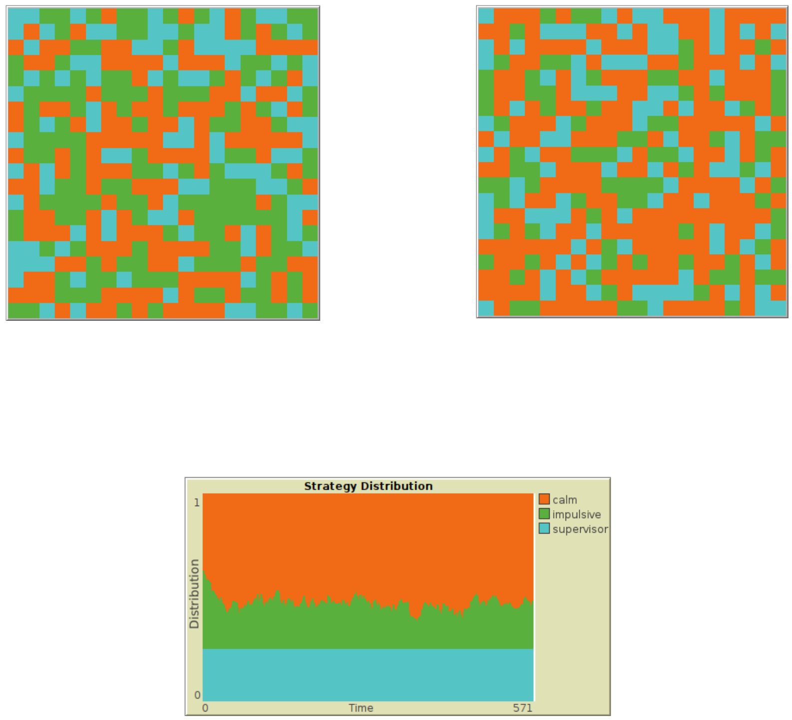


Fig. 1. Initial population, final population and distribution graph for this experiment. The test was carried out with an initial population of 150 calm, 150 impulsive and 100 supervisors and a revision probability of 30%. The number of impulsive players is reduced but is not negligible.

The next tests were performed on the model by changing the initial distribution of the population to search for possible tipping points.

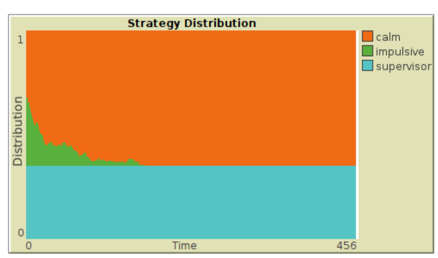


Fig. 2. Initial population, final population and distribution graph for this experiment. The test was carried out with an initial population of 130 calm, 130 impulsive and 140 supervisors and a revision probability of 50%. The number of impulsive players reaches 0.

The tipping point, for the calm individuals to replace entirely the impulsive ones, occurs when the supervisors are around 135 and calm and impulsive individuals are equally distributed. Higher probabilities of revision makes the model reach the equilibrium faster.

Next, I performed some experiments using different initial distributions.

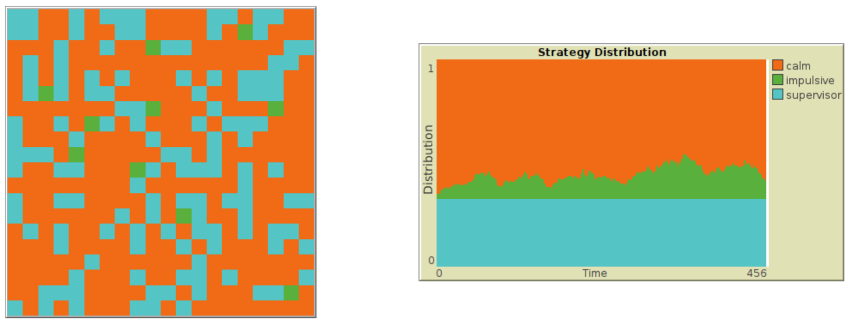


Fig. 3. Test with an initial population with a prevalence of calm players. Number of supervisors: 130, Calm players: 260, Impulsive players: 10

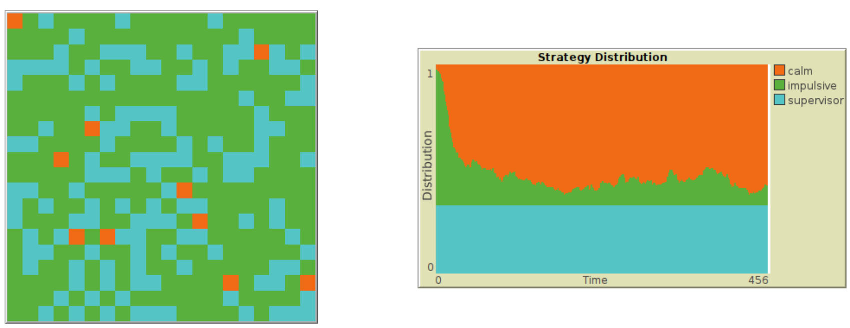


Fig. 4. Test with an initial distribution with a prevalence of impulsive players. Number of supervisors: 130, Calm players: 10, Impulsive players: 260

By changing the initial distribution, the dynamic of the simulation does not change much. The model reaches the same equilibrium as before, just from a different starting point. If the population is mostly calm, then impulsive players have initially an advantage as they are dominant against calm ones. On the other hand, if the population is mostly impulsive at the start of the simulation, then there is a huge increase of calm players. Indeed, even if calm players are very few, they have an higher payoff if they play with supervisors in a mostly impulsive population where players often fight each other.

What is really interesting from this tests is the role of supervisors. They help reduce the number of impulsive players. For this reason, their number is a critical hyper parameter in the model. It is therefore important to perform some experiments to assess their effect on the simulation.

In populations where calm and impulsive players are equally distributed, the number of supervisors affect the final distribution of impulsive players.

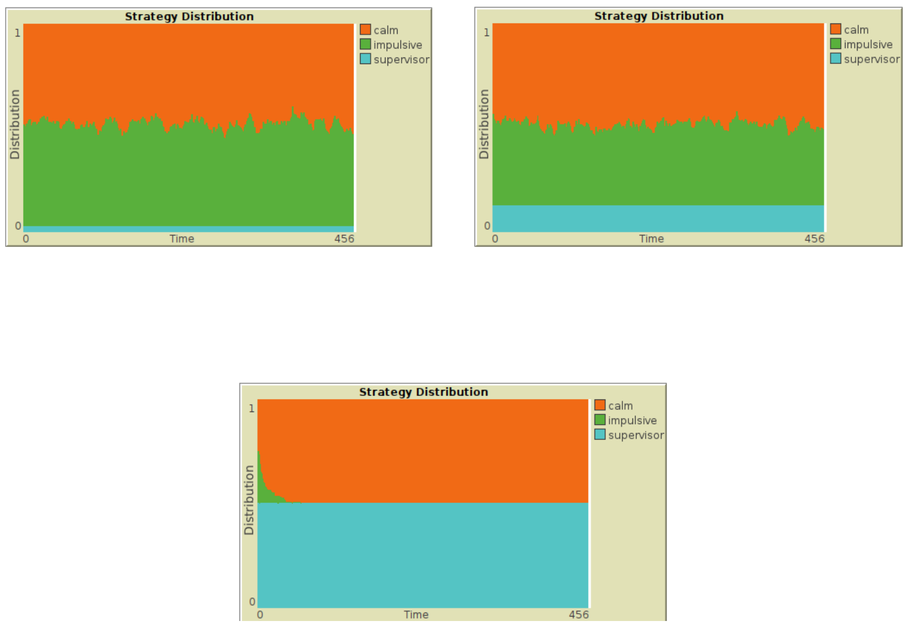
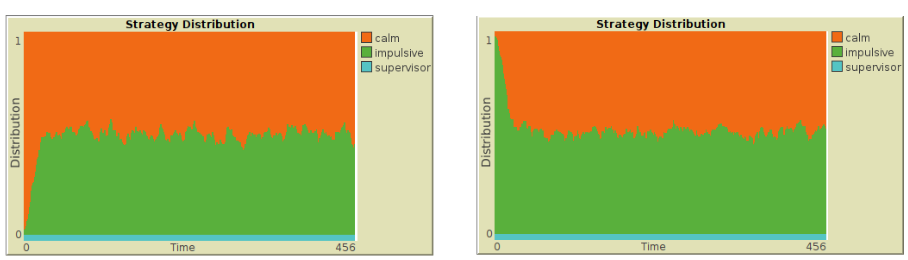


Fig. 5. Tests with different numbers of supervisors. The number of final calm players is always the same, but impulsive players change. In a way supervisors replace impulsive individuals.

The same phenomenon happens when players are not equally distributed initially. Increasing the number of supervisors, affects the final number of impulsive players.



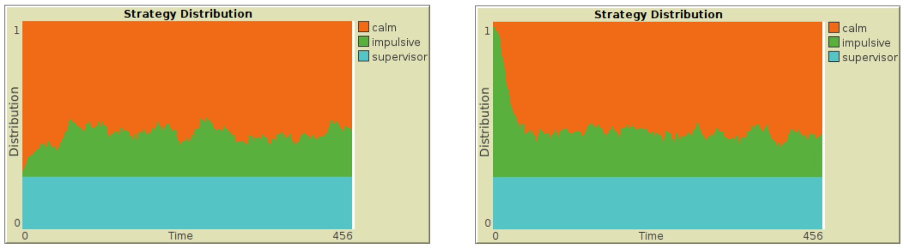


Fig. 6. Tests with different numbers of supervisors and different initial distributions. The final number of calm players remains the same. The number of impulsive individuals at the equilibrium is dependent on the number of supervisors.

4 Local Game

The experiments performed thus far allowed every player to select a random player from the population to play with and to revise their strategy. This type of game is not very realistic if we consider a true evacuation scenario, where people can interact only with the other people nearby. The model has then been changed to account for this aspect of real evacuations.

Every player can only play with their direct neighbor and, when revisiting their strategy, they can only watch a neighbors' strategy. This model fosters the formation of groups of impulsive neighbors. Indeed, impulsive individuals are dominant when playing with calm individuals and, if they are in a group, can enforce each other to continue their behaviour. Note that it is possible to make an analogy with a phenomenon also present in real life scenarios where, the behaviour of one impulsive person, is reinforced by its neighbors who start acting the same way.

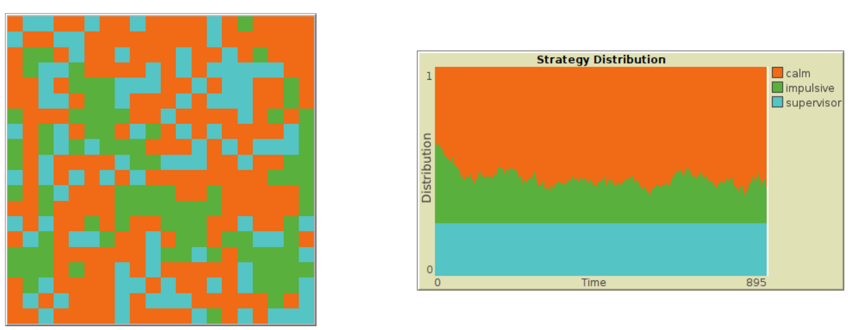


Fig. 7. Test performed on the model with the local game. The first picture show the population after 500 time steps. As expected, in the simulation are present groups of impulsive players, in a larger population of calm players.

The experiments performed on this model show that, using this type of local game, the model reaches the equilibrium even with a smaller number of supervisors. The probability of revision affects heavily the model performance. For this local game, having an higher probability of revision reduces the tipping point for the number of supervisors. Indeed, when groups of impulsive players form, they can be infiltrated more easily by calm neighbors playing with supervisors.

With a probability of revision of 10% the tipping point for the model to eliminate impulsive players is around 130 supervisors. By just increasing the probability to 20% the tipping point lowers to 120 supervisors. If the probability of revision reaches 90% the tipping point reaches 110 supervisors, a significant decrease.

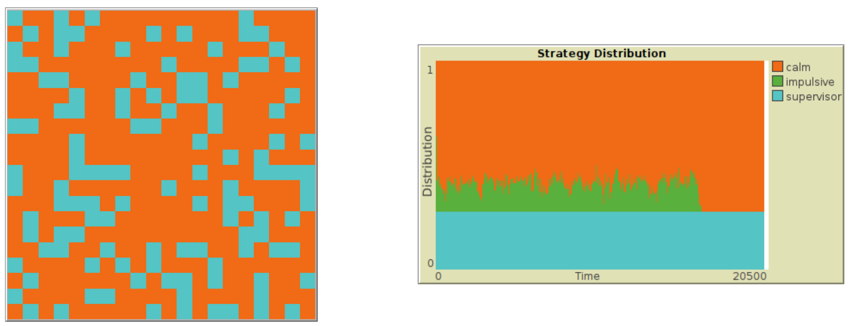


Fig. 8. Test with 110 supervisors and a probability of revision of 90%. Higher probabilities of revision correspond to lower tipping points for the number of supervisors.

In general, if we are playing a local game, the model reaches an equilibrium without impulsive players with less supervisors. If, instead, the model has too few supervisors to get rid completely of impulsive individuals, the number of these is higher than when playing a global game. This is caused by the formation of groups of impulsive players that reinforce each other.

4.1 Place Ordered Supervisors

By now, it is clear that supervisors have a really strong influence on the outcome of the evacuation. It is therefore important to find techniques to improve their effectiveness even more. One of the most common strategies to make an evacuation and really, any kind of crowd activity, more efficient, is to place supervisors in strategic positions in order to improve their capability to control other people. Note that this strategy only works if the game is played locally, between neighbors, otherwise the position of supervisors does not matter.

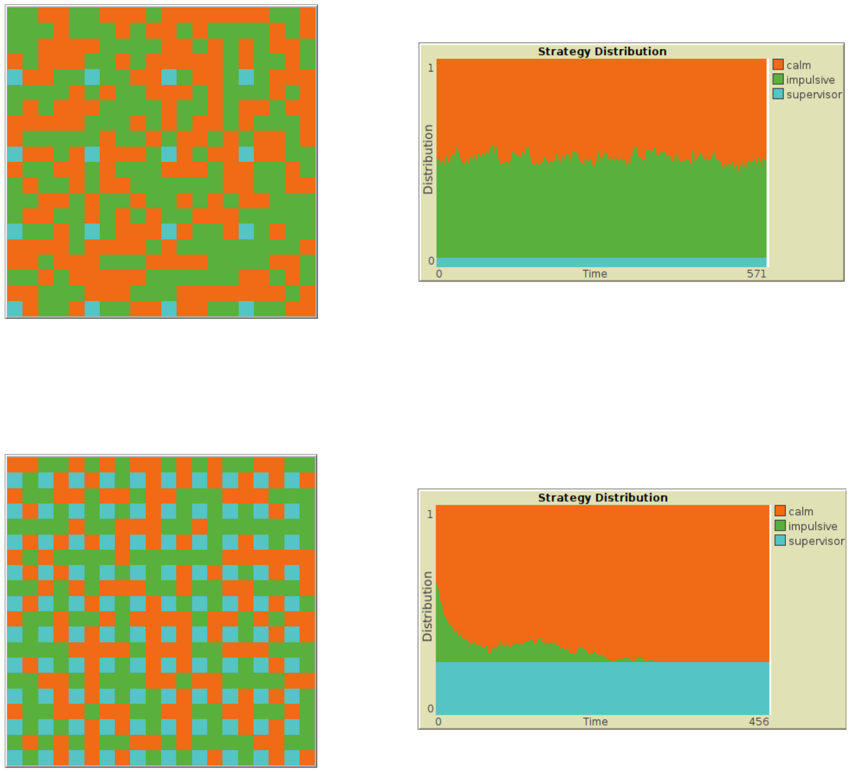


Fig. 9. The first test uses only 16 supervisors and the model does not converge. The second test, with 100 supervisors, eliminates every impulsive player.

As we can see from the experiments performed with this model, by ordering the position of supervisors in a proper way, we can help the simulation reach a state without impulsive individuals. Indeed, the 100 supervisors used in the test, are still a low number compared to the 130 needed for the model to converge in normal scenarios. With this relatively low number of supervisors, the simulation converges to a good equilibrium.

This experiments confirm the importance of placing supervisors in strategic positions. It is clear that this kind of placing makes it possible to reduce the number of supervisors needed to accomplish an orderly evacuation.

5 Noise

To account for unpredictable behavior of players in the simulation, noise was added to the process of changing a player's strategy. After every round of games, every player chooses a random strategy with some probability, otherwise it watches another player.

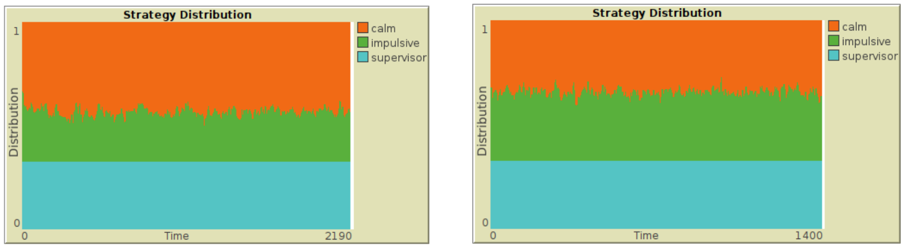


Fig. 10. By adding some noise, the number of impulsive players, at the equilibrium, increases. The first test is performed with a noise value of 10% whether the second with a value of 50%

The tests performed with this model, show the effect of noise on the final equilibrium of the simulation. The higher the probability of choosing a random strategy, the higher the final number of impulsive players. Noise, indeed, fosters the creation of impulsive individuals and makes it harder to reach a good equilibrium. With noise, the simulation can not reach a state without impulsive players.

Adding noise to a simulation is also important in order to verify the robustness of its characteristics. The properties found thus far that are no more valid if some noise is added, are not relevant to our study.

For this reason, we make some experiments to verify the role of supervisors in a noisy simulation.

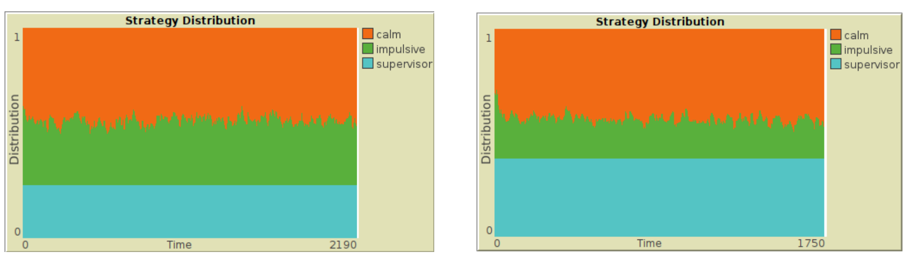


Fig. 11. Tests with noise set to 10%. In the first one the number of supervisors is 100, in the second 150. The percentage of impulsive players at equilibrium is 30% in the first test and only 20% in the second.

Even if the model does not eliminate impulsive players completely, increasing the number of supervisors has still the effect of reducing them. This is a confirmation of the findings previously exposed.

More experiments were performed to test the role of good supervisor placing.

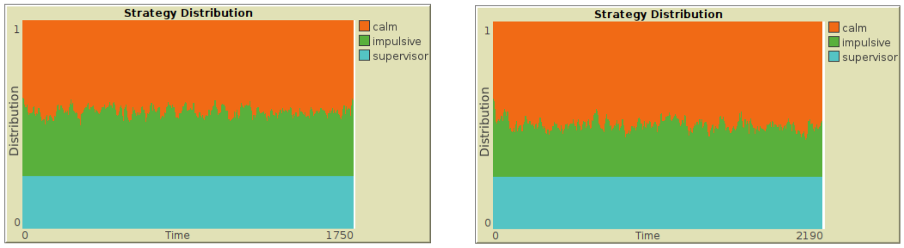


Fig. 12. Tests with noise set to 10% and number of supervisors 100. In the first test supervisors are placed randomly, in the second they are placed in an ordered manner. The percentage of impulsive players at equilibrium is 25% in the first test and only 20% in the second.

The tests conducted in this manner confirm the importance of strategic supervisor placing. Even if the reduction of impulsive players is less noticeable, the effect is still present even with noise, confirming the finding of this work.

6 Retaliator

Thus far, individuals have been categorized as calm or impulsive but, in real scenarios, calm people may react impulsively when someone is trying to steal their place in line. It is necessary to model another type of player: a retaliator. A retaliator, is a person who acts calmly when interacting with calm persons but may act impulsively when interacting with impulsive persons.

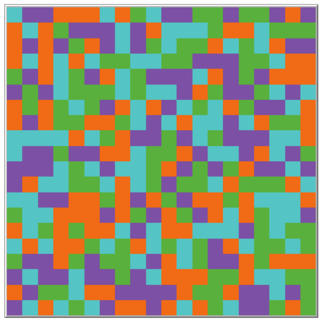
The new payoff matrix that includes the retaliator is therefore defined as:

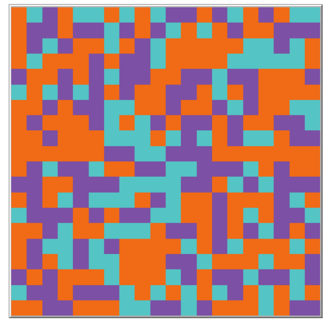
Table 2. Payoff matrix for the evacuation game, including the retaliator

	Calm	Impulsive	Retaliator	Supervisor
Calm	1	0	1	2
Impulsive	2	-1	-1	0
Retaliator	1	-1	1	2

The retaliator always acts as a calm person except when playing with an impulsive person.

In this model, the retaliator is represented by purple patches.





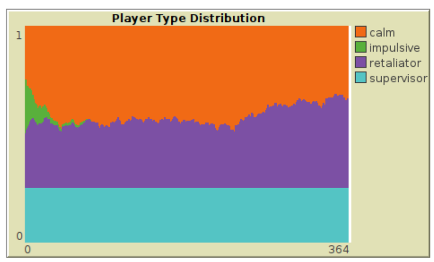


Fig. 13. With an initial population in which players are equally distributed, impulsive individuals quickly disappear. Calm players and retaliators oscillate depending on the particular instance.

From the first simulations it is evident that retaliators and calm players are dominant against impulsive players. Indeed, in this situation, impulsive players get a low payoff both from playing with calm players and retaliators. When impulsive players disappear from the simulation, calm players and retaliators are equivalent. We can try to balance the simulation by increasing the number of impulsive players.

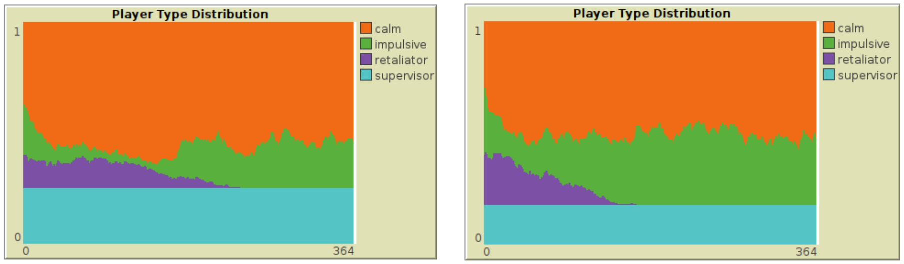


Fig. 14. Mainly calm populations are more favorable to impulsive players. First test distribution: 150 calm, 90 impulsive, 60 retaliators, 100 supervisors. Second test distribution : 120 calm, 120 impulsive, 90 retaliators, 70 supervisors.

When the population is made of many calm players, impulsive individuals have an advantage as they can cut in line easily. This way, the model reaches an equilibrium without retaliators. In this instances, retaliators tend to disappear as they are slightly weaker than calm players and can not compete with impulsive ones.

When, instead, there is a majority of retaliators and impulsive players then, calm players and retaliators, receive better payoffs. The nature of retaliators is, indeed, to adapt to the behavior of their co-players. Their payoff depend heavily on the distribution of the population.

7 Conclusions

I have built an agent-based model to simulate interactions between individuals in an evacuation scenario. I used Evolutionary Game Theory techniques to study the behavior of the model.

This study showed that supervisors have a crucial role in the control of impulsive individuals and that more supervisors equals to less impulsive people in the simulation. It is also evident from the simulation that, if the number of supervisors reaches some threshold, the simulation can reach an equilibrium without impulsive people.

A more realistic simulation was built, with every player using only its neighbors to play instead of the whole population. It appears that, placing supervisors in strategic positions, helps in reducing the number of impulsive players if playing a local game. This results shed some light on the role of supervisors in real world evacuations.

Adding noise to she simulation does not invalidate all the previous findings, giving a confirmation of the results obtained with this model.

Finally, adding a new type of player, the retaliator, makes the model more complete and capable of representing different scenarios.

In conclusion, the model hereby presented, is capable of modeling a few different scenarios that often arise from the interaction of people during emergencies. Using this type of simulations, it is possible to study safety measures that can be undertaken to make evacuations faster and more efficient, possibly reducing casualties.

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