Crowd Egress Simulation

CS166 – Fall 2019

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Introduction

The goal of this paper is to model a situation in which a room needs to be evacuated after a fire alarm went off. The model is generated using object-oriented programing in Python and implementing cellular automata. There are multiple rules and assumptions based on which the room is evacuated and randomness is strategically incorporated where needed. Finally, a Monte Carlo simulation of the random process is created and the results are interpreted by analyzing distributions generated using the simulation.

Model and Simulation Description

Rules

The room is initialized with a specific number of people at different places in the room where only one person can be found at one particular place. The room is set as a two-dimensional grid where each cell represents a space for one person which may or may not be occupied. The model is updated each step at a time and the nodes are synchronously updated. The time is accounted for in the form number of steps it takes for the room is emptied. The synchronous updating is a realistic method in this case because at the time of evacuation each person tries to move at the same time. In order to move, each person first calculates the cost of moving and chooses to move in the direction which has the least cost. The moving costs are calculated using the horizontal and vertical distances from the nearest midpoint of the exit[1].

Assumptions

In this scenario, it is assumed that each person in the room is a rational human being who makes smart decisions for calculating the best path for themselves that will make them leave the room the quickest. The model also is running under the assumption that the humans in the room are similar in terms of their characteristics like fitness, built and agility. Based on this assumption, each human in the room also takes similar kinds of steps, in that, they move one step at a time which corresponds to moving from one cell to the other. These assumptions simplify this very model but will not hold true in cases when the audience of the room is diverse in the sense of different ages, stamina, disabilities, health conditions, etc. In those cases, it would be insightful to incorporate differences in speed and other characteristics that define the movement of people in the room.

Parameters

1. **Number of people in a room**

This parameter is implemented in the simulation which takes up an integer value to initialize the number of people in the room. This is an extremely crucial parameter because the people are the most significant entities in this model. The different number of people in a fixed-sized room is predicted to have a strong effect on the certain output metrics that will be discussed later in this paper.

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[1] This is more rigorously commented on and explained in the notebook.

2. **Number of exits in a room**

This parameter is implemented in the simulation as an integer value which defines the different number of locations through which people can leave. The number of exits is, again, extremely crucial because the count of these exits and their placement is going to affect how efficiently people evacuate the room in the modeled scenario. The number of exits is going to determine the pace at which people leave the room and it predicted that more the number of exits the easier it will be to evacuate the people especially in the case when exits are strategically placed on different parts of the room.

3. **The size of the room**

The size of the room is basically representative of the dimensions of the grid which models the room. It is a tuple that gives the width and length of the room and allows the model to set up a two-dimensional space. The size of the room will also impact the efficiency with which people evacuate the room but it also depends on how the people are populated at the initialization step of the model. If the people are mostly towards the center of the room, and it is a huge room, the time to evacuate the building would be greater in that case.

4. **The size of the exit**

The size of the exit is another important parameter that is implemented as an integer value which represents how many cells (either vertically or horizontally) do the exit point cover. For example, if the exit size is 1, then the exit point would cover only one cell of the grid. The greater the size of the exit, the easier it would be for multiple people to exit from the same boundary/wall of the room.

<u>Output and Measurements</u>

The scenario for this project is to evacuate people from a room where a fire alarm has gone off. Given the urgency of the situation, the most crucial output is the time (which discretized to simulation steps in this case) it takes for everyone to evacuate the room. Therefore, the simulation is tested for the time it takes for the room to be evacuated based on different configurations of the parameters described above. In order to gauge a better sense of each parameter, most of the tests are conducted such that only one of the conditions is changed while the rest remains the same. To measure the effects, the use of plots, histograms, confidence intervals, and descriptive statistics is made.

Interpretation and Analysis

As mentioned above, the most significant quantity of interest, in this case, is the time it takes to evacuate the room entirely. The following plots are generated to understand the relationship between the aforementioned parameters and the time taken to evacuate.

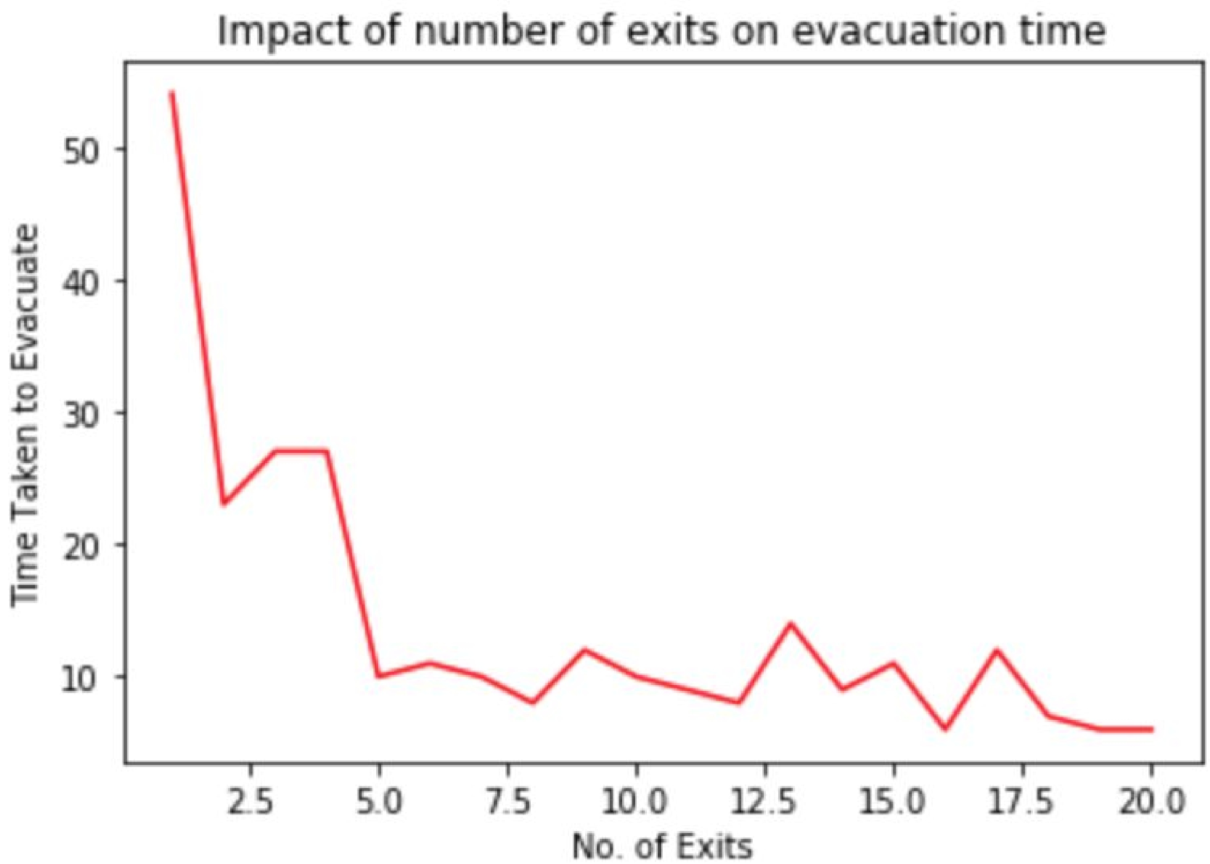

Figure 1: A plot showing how the number of exits in the room affects the time taken to evacuate the room.

The plot shown in figure 1 is confirming the prediction regarding an inverse relation between the the number of exits and teh time taken to evaluate i.e. the greater the number of exits, the more the options for people to leave the room quickly. This is explained by the fact that it avoids steps where two people have exact same distances from the exit door but since only one of them can go, the other will have to wait for the next time step. The plot above is the scenario with 30 people present in the room that is 10×10 in dimensions and has the exit size of 1. Despite the general trend showing a decrease in time with greater number of exits, there are some bumps in the graph which can be explained by the different configurations of the way the room is populated. There might be situations when even though the number of exits is greater, there are more chances of collisions between people due to their layout and thus time is wasted.

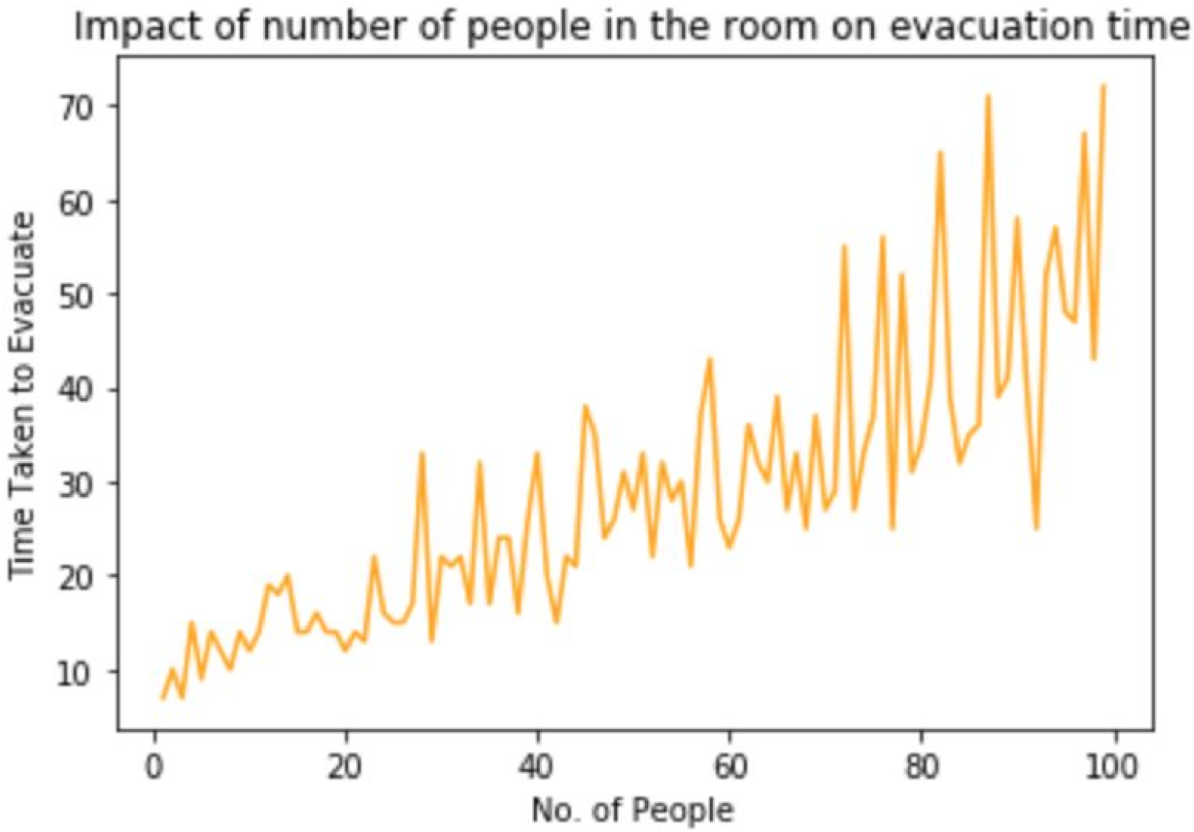

Figure 2: A plot showing how the number of people in the room affects the time taken to evacuate the room.

The plot in figure 2 is obtained by generating 5 exits in a square room that can host 225 people at most and the size of each exit is 1. As predicted, there a positive relation between the number of people in the room and the evacuation time, in that, as the number of people increase, the time to leave also increases. This is justified by the fact that the more the people in the room, the higher a chance of people bumping into one another and thus taking longer to evacuate the room. As observed in the previous plot, the graph is fluctuates grately but that is primarly because other confounding variables such the layout of people and the exits that account for faster exit even when the room is crowded.

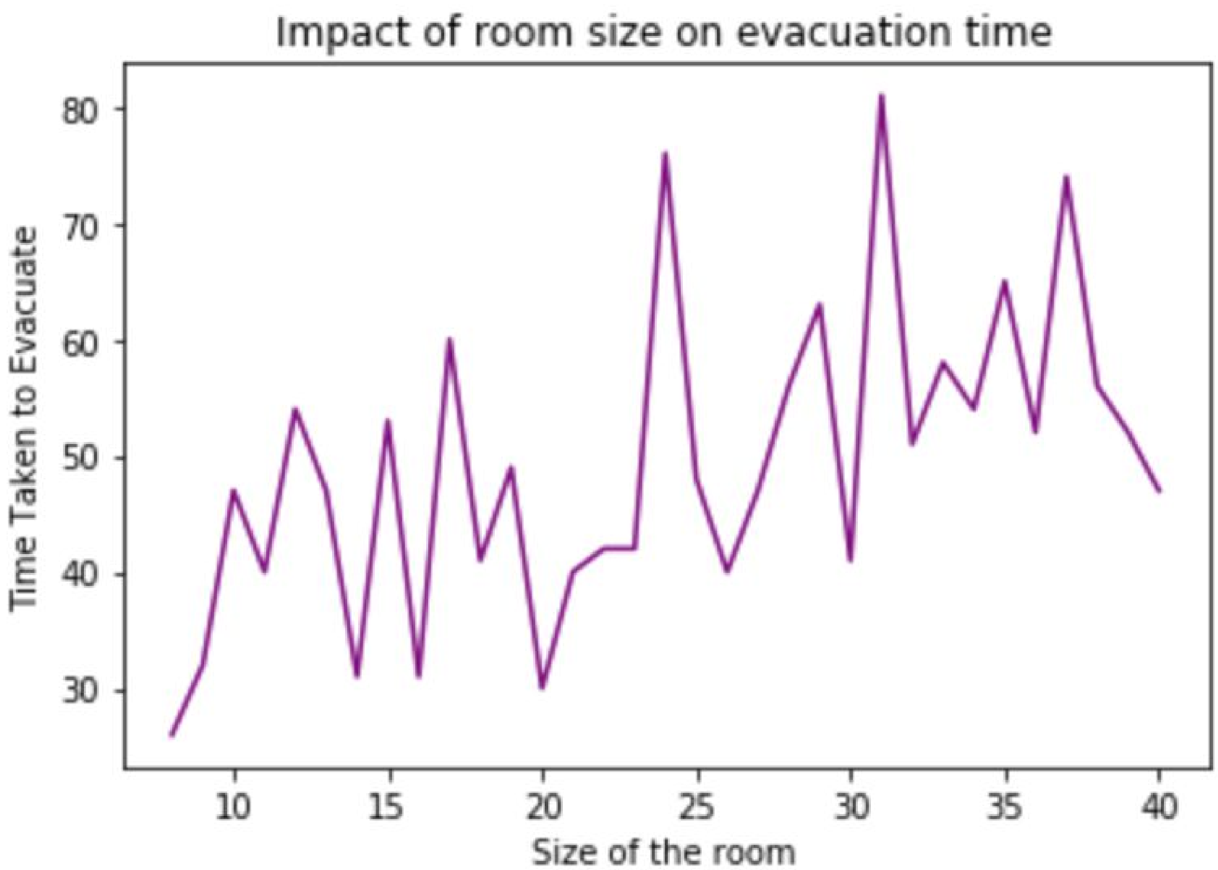

Figure 3: A plot showing how the size of the room affects the time taken to evacuate it.

While the there is an overall increase in the time taken to evacaute when room size increase, the trend is fluctuates a lot and thus the deduction is not comprehensive. These fluctuations account for scenarios like the case of having a big room but also most people are already at the exits or close to it since they are randomly populated.

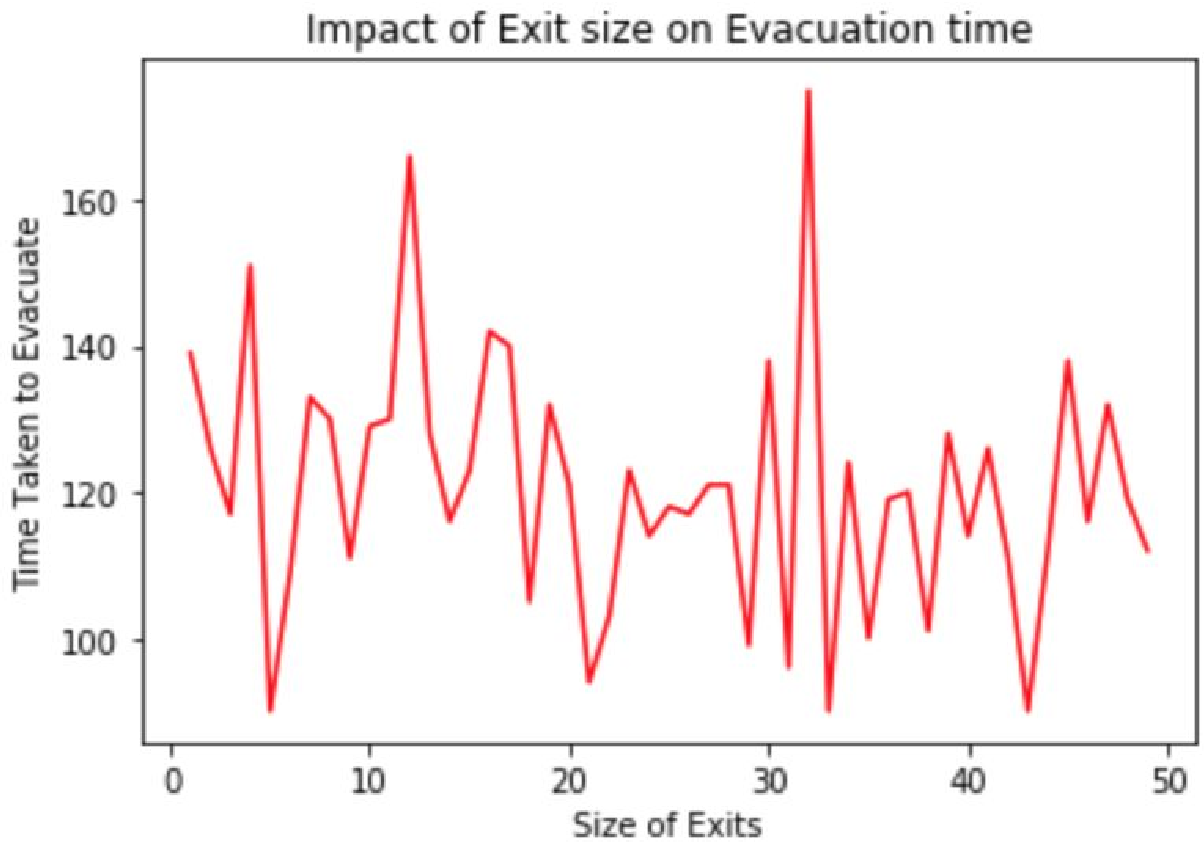

Figure 4: A plot showing how the size of exits in the room affects the time taken to evacuate it.

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Similar to the plot above, even though the overall time to leave the room decreases with an increase in the size of exits, the trend fluctuates a lot to conclusively state the relation between the two. Generally speaking, the plot does not offer a realistic scenario because it is highly uncommon to have such huge exits to begin.

Distribution

To further analyze the relations above the power of computational simulations is used to run it a thousand times and histograms are generated to see what the distributions look like.

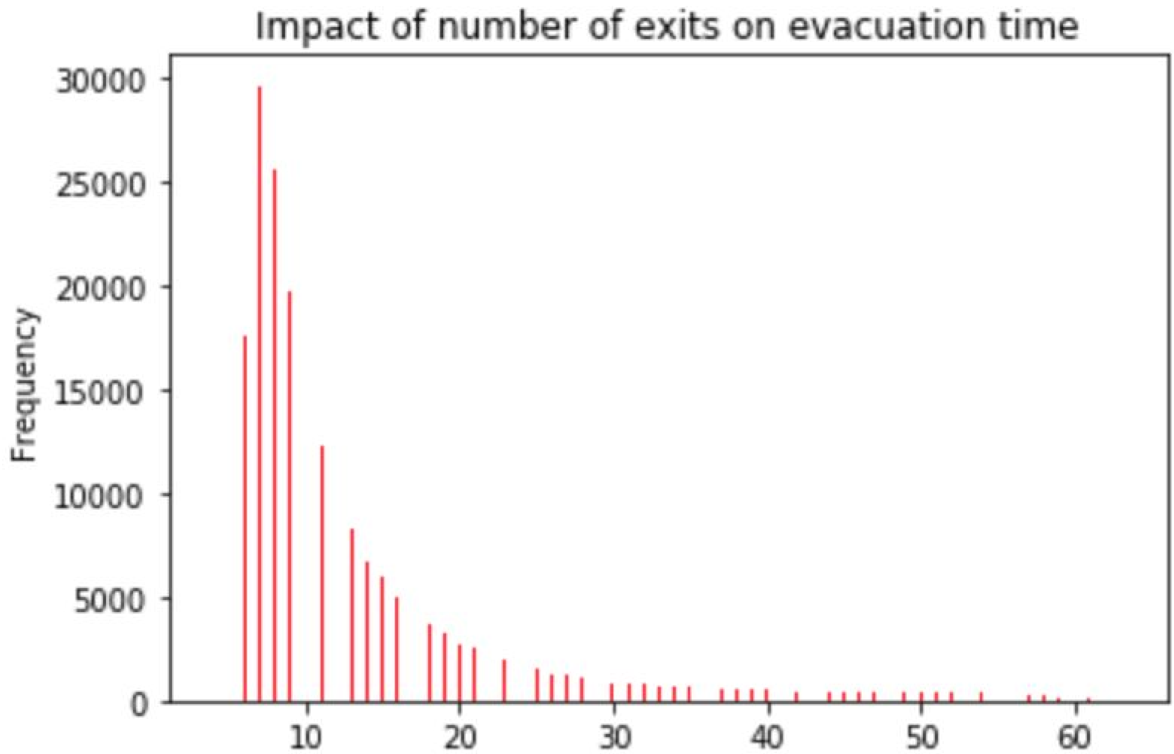

Figure 5: A distribution showing the effect of number of exits on evacuation time.

The histogram above forms a right-skeweed distribution which has a skewness of 2.46 which indicates a quite a heavy degree of skewness. The mean of the distrubution is 13.53 and a variance of 96.6. The histogram also tells us that is a unimodal distribution in which the mode is around 8 (less than the mean and hence the right skew). The distribution confirms the interpretation done above in that there are very small frequencies for greater number of time steps as the exit count increases.

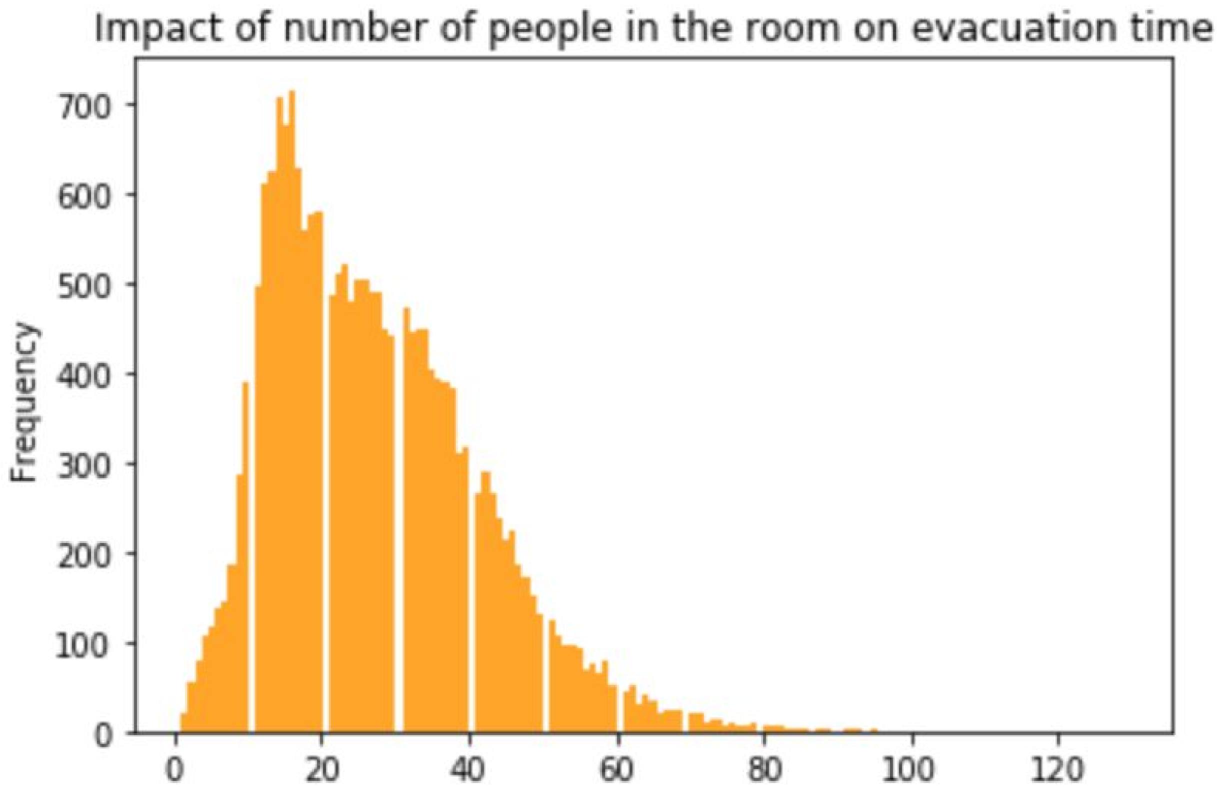

Figure 6: A distribution showing the effect of number of people in the room on evacuation time.

The histogram above forms a right-skeweed distribution which has a skewness of 0.82 which indicates a much less degree of skewness than the distribution seen above. However, the mean of the distrubution is 27.2 with a variance of 199.9 which greater than the previous distribution.

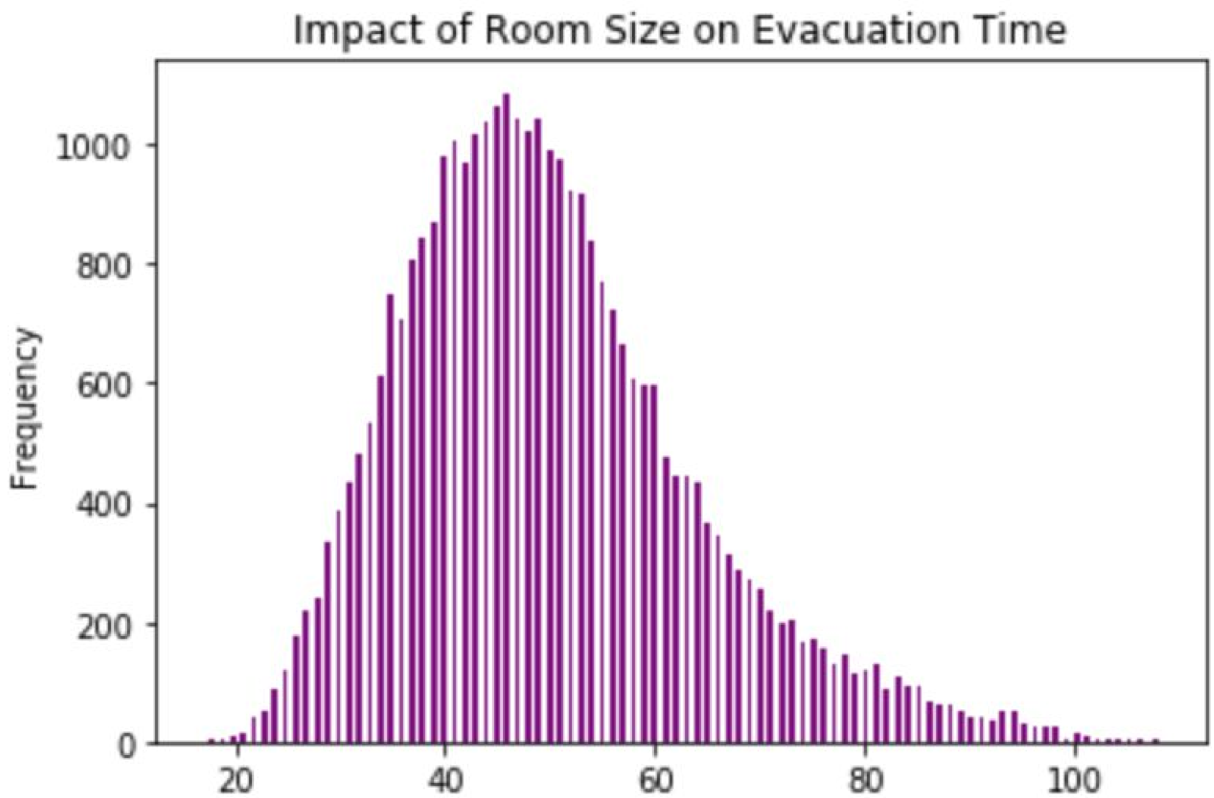

Figure 7: A distribution showing the effect of number of people in the room on evacuation time.

The histogram above also forms a right-skeweed distribution but with the least amount of skewness i.e. 0.79. The mean of this distribution is 50.1 with a variance of 202.4 which are the greatest among the three distributions generated in this paper.

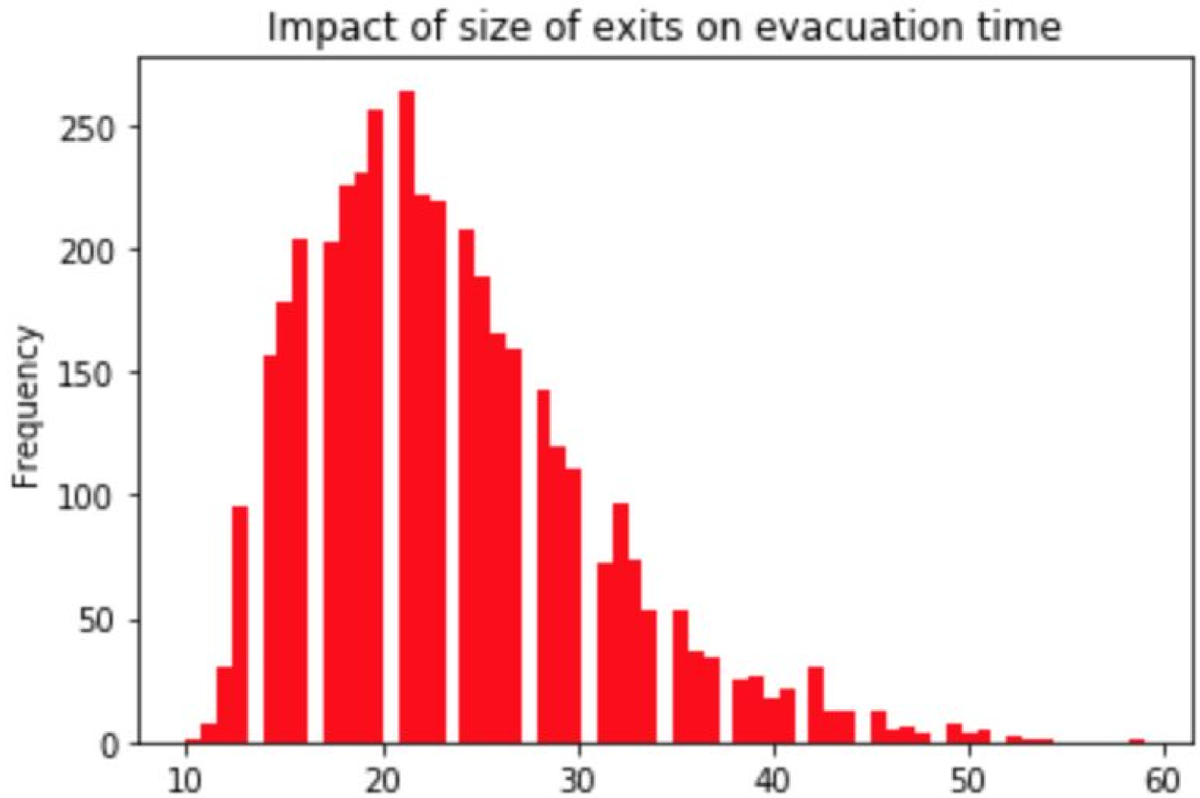

Figure 8: A distribution showing the effect of the size of exits in the room on evacuation time.

Comparisons

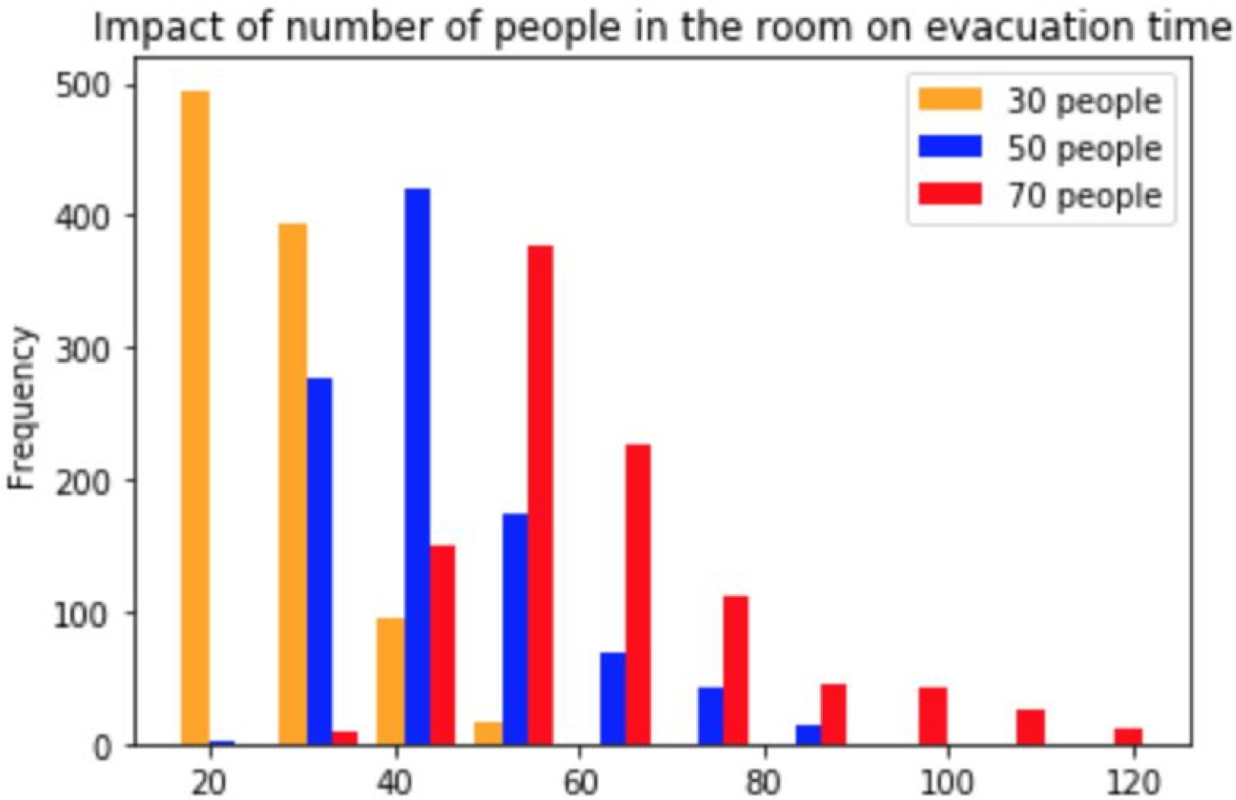

Figure 9: A comparison of histograms obtained when 30, 50 and 70 people are present in a room with others parameters appropriately fixed.

The histograms in figure 8 compare how different population sizes explain the behavior of the simulation when the room is 10×10 grid with 2 exits and each exit has a size of 1. These variables are fixed as such based on how rooms are generally configured. Usually, there is a back and front exit (hence 2 exits) and the doors are standard sized (hence 1). The comparison of these histograms indicate the anticipated results in that, the greater the number of people, the more common it is to see frequencies with higher time steps (in red).

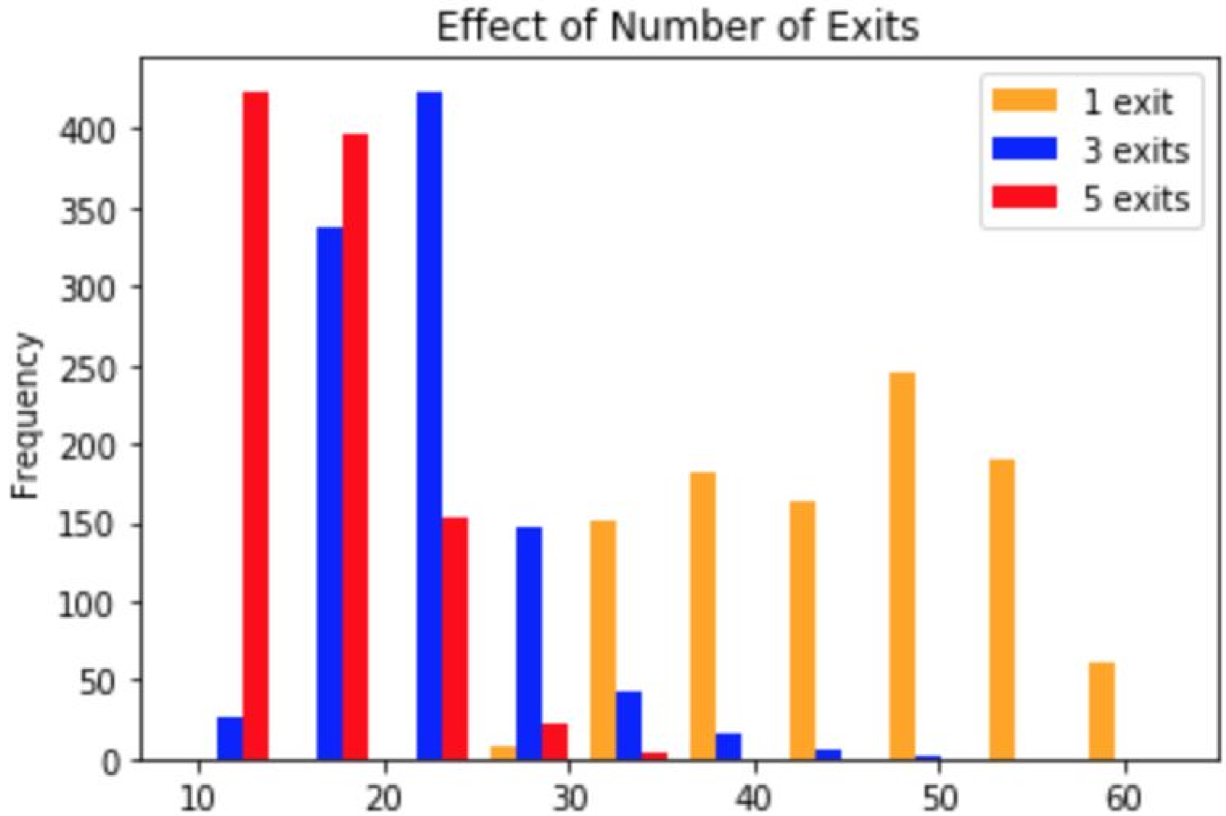

Figure 10: A comparison of histograms obtained when 1,3 and 5 exits are generated in a room with others parameters appropriately fixed.

The histograms in figure 9 compare how different number of exits explain the behavior of the simulation when the room is 10×10 grid with 30 people and each exit has a size of 1. The number of exits do not go beyond 5 for this comparison because it unusual for a room to have so many exits especially is it only holds a maximum of 100 people.

The comparison of these histograms indicate the anticipated results in that, the greater the number of exits, the more common it is to see frequencies with smaller time steps (in red) whereas the yellow bars are generally towards the right side (indicating more time taken to evacutate with smaller number of exits).

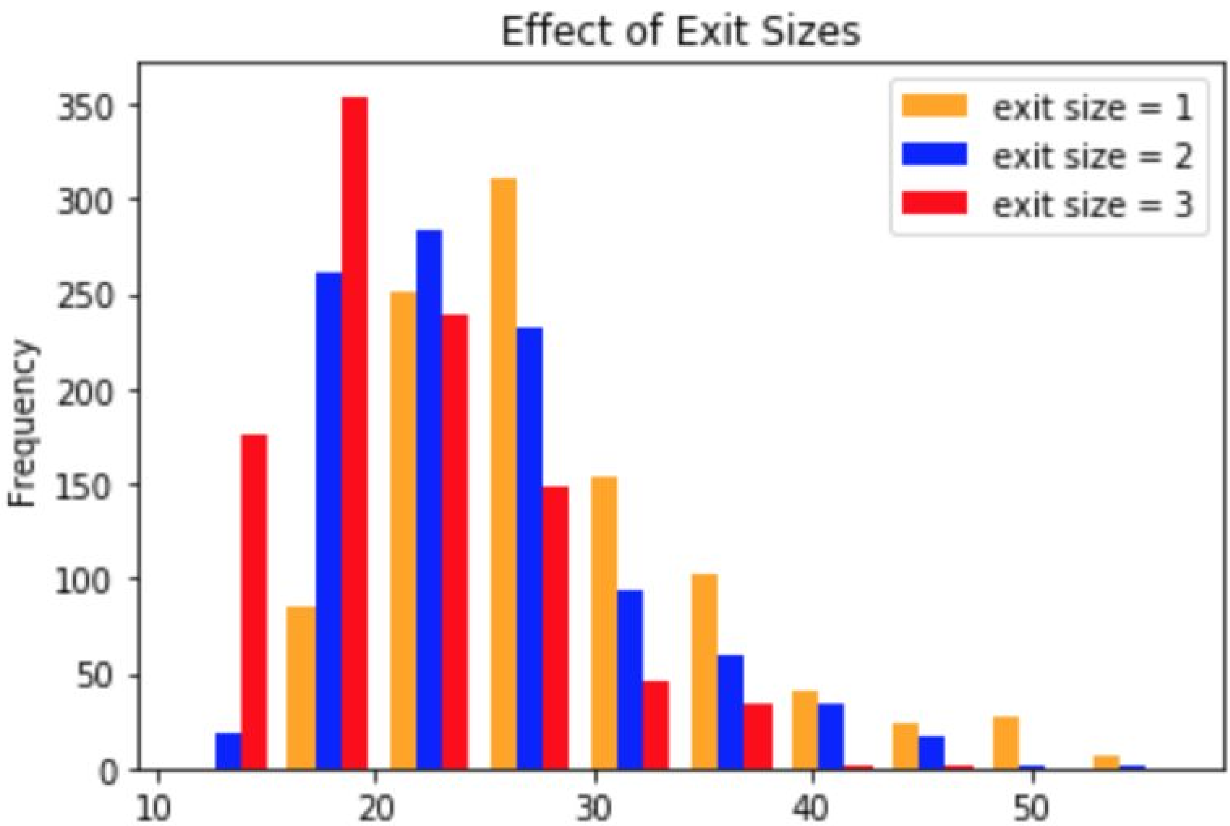

Figure 11: A comparison of histograms obtained when the sizes of the exits are 1, 2 and 3 with others parameters appropriately fixed.

The histograms in figure 10 compare how different sizes of exits explain the behavior of the simulation when the room is 10×10 grid with 30 people and 2 exits. The comparison is among the sizes 1,2 and 3 because otherwise doors would be abnormally wide which is farther from reality.

Just like in previous comparisons, the results show what expected – the greater exit sizes mean that most of the red bars will have higher frequecies on the left-hand side because they allow quicker escapes from the room as opposed to the yellow bars that show greater frequencies for higher number of steps than red ones.

Recommendations

The plot in figure 1, despite being simple, is quite insightful in helping us realize that the greater number of exits generally allow a much quicker evaluation process. In cases when they do not, it's usually because of the distances of those exit locations from the people in the room which needs to be strategically adjusted when designing rooms in buildings. The location of exits is an important consideration that needs to be made as diverse to allow multiple different paths for a single person to leave with minimal hinderances in their way. Furthermore, the analysis of figure 1 and 2 in conjunction allows us to understand the importance of planning the number of exits based on the number of people a room is most likely to host. The two parameters have can complement each other well because with more exits, there are lesser chances of two people having to compete for one common exit between them and thus additional steps can be avoided.

When designing rooms, it is is also helpful to prominently mark exit points which are not obstructed by anything. This would allow people to know from a distance as to which exits are closest to the and thus save time. The dimensions of the room must be an imporatant consideration when determining the number of exits that is needed to evacauate the room. In larger rooms, it is not recommended to have one or two exits but instead there must be multiple exits at different boundaries of the room to allow access to more people in one time step. Additionally, it is aslo important to consider the way a room is going to be utilized and by how many people. For instance, if it is a ball room, people are more likely to be spread out accross the room and thus having an exit on each side of the room might be helpful.

Uncertainties and Limitations

Confidence Intervals

A great advantage of running Monte Carlo simulations is that it allows one to be certain (or not) about their results using metrics like confidence intervals. Confindence intervals are more insightful than point estimates because using the upper and lower bounds, the true mean can be attained 95% of the time. Table 1 below summarizes the confidence intervals and the uncertainity of these results. The uncertainity is esentially a measure of how wide the range between lower and upper bound of the confidence interval is and thus computed by finding the difference between the two.

	Lower bound	**Upper bound**	**Difference/ Uncertainity**
No. of Exits	13.48	13.56	0.09
No. of People	27.04	27.43	0.39
Room Size	49.68	49.98	0.30
Size of Exit	23.34	23.78	0.44

Table 1: A summary of the 95% confidence intervals and uncertainty after running the simulation.

The table indicates how the simulation testing the effect of the number of exits in a room give the most certain results since it has the smallest difference between the bounds i.e. 0.09. However, these results can be further improved by running the number of simulations for an even greater number of times. Furthermore, the entire model is simplified to an extent that makes it easier to implement but in reality there are many other factors that contribute to different results if accounted for.

The model can be made more complex by incorporating factors like multiple obstacles in the room that slow down the rate of evacuation. Morever, the attributes of each person in the room are not necessarily going to be the same and not everyone will be able to deal with chaos as well. An interesting way to improve this model would be to see what impact does the speed of each person has on the way people evacuate and what would happen if there is a stampede in the room. Nonetheless, this model does the fundamental job of analyzing ways people evacuate the room given the scope of this course.

HCs

#psychologicalexplanation and **#multipleagents**: The entire model is based on how humans interact in crises such as the evacuating a room during a fire hazard. When describing the situation being modeled, the way multiple agents think from both a rational and emotional perspective in these events was an important factor to come up with assumptions and improvements for this model. The interaction of one agent with another in this scenario was determined based on Maslow's Hierarchy of Needs where safety needs are second-most fundamental for rational human beings. People plan their exits based on their distance from the exit locations in the model to survive the hazard and they would also need to account for potential obstacles on their paths.

#professionalism: I have abided by the gudilines presented in the assignment instructions to generate this model and test out simulations. I have neatly organized this report with figures and tables and their appropriate captions.

#analogies: When modeling this scenario in python code, I was able point out similarities in the real life and cellular automata. Interesting analogies like modeling a room using a 2 dimensional grid is what allowed to make this model realistic.

#descriptivestats: In order to describe the distributions after running the simulations, I have used mean, variance and skewness as measures to explain how the predictions and interpratation of plots compare to the distributions. By accurately computing these metrics, the description is quantified and is easier to follow.

Appendix

Python Code (attached below)