COVID-19 Social Distancing Simulation with Supermarket Case Study

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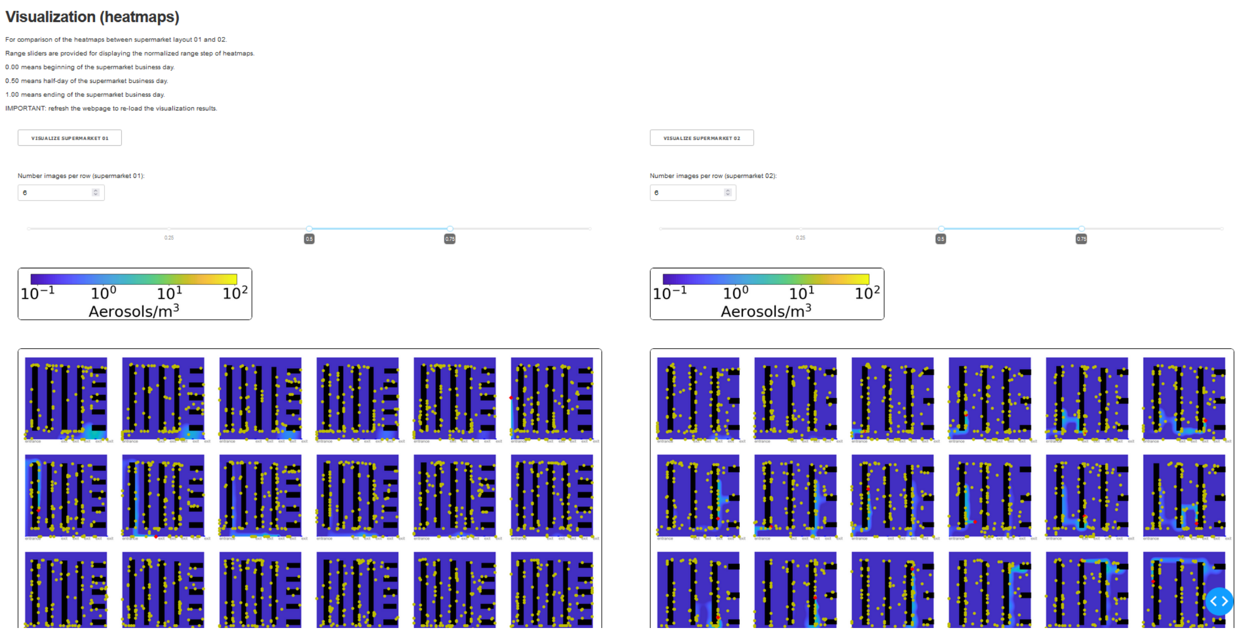

Fig. 1: Visualization tool dashboard.

Abstract—A visualization tool will be developed to assist store owners and policy makers with decisions based on indoor aerosol spread of covid-19. In this project, we develop the interactive visualization tool for a scenario concerning a supermarket. The tool is developed by using Python Dash. The tool provides the user to create the two supermarket layouts on the canvas and then convert to PBM format for running the simulation. Parameters such as number of visited customers, entrance location, number and location of exits, and facemask types are available to be set by the users. The visualizations of cumulative heatmaps and number of customers exposed to several aerosol levels can be displayed on the dashboard. We have designed three scenarios to study the effects of supermarket layouts, facemask types, and number of exits on the contagious of the COVID-19 within supermarket. Simulation results show that the customers without wearing facemask and low number of exits increased the risk of COVID-19 infections.

Index Terms—COVID-19, interactive visualization tool, supermarket

1 Introduction.

A very relevant topic currently is the COVID-19 disease caused by the novel SARS-CoV-2 coronavirus, with over 400 million confirmed worldwide cases by February 2022. The disease's severity ranges from asymptomatic to life-threatening respiratory symptoms, with over 5 million globally reported deaths to date [9]. For the prevention of SARS-CoV-2 transmission (which is mostly by large droplets [8]), good hand hygiene and social distancing have been emphasized mostly [5]. The possibility for airborne transmission was discussed in various research communications [4] [6] [3].

In this project, an interactive visualization tool is going to be developed to visualize the simulation of COVID-19 spread mechanisms in a supermarket. With this tool, the policymakers will be able to obtain informative insight and data for evaluating the effectiveness of certain social distancing measures in a supermarket for several scenarios. This interactive visualization can serve as a decision support tool for policymakers and grocery store owners. The model used as the basis for the visualization is the one developed by Vuorinen et al. [8].

This interactive visualization tool can be used to answer the following questions:

i What factors are likely to play a crucial role in the spread of the virus?

ii How many customers can be in the store without significantly increasing the risk of infection?

iii How does the store layout or floor plan influence the virus spread?

iv How can we visually compare different scenarios?

v What is the probability of a customer getting infected after a trip to the store?

2 Requirements

To ensure that the visualization tool can actually be used to answer the questions in section 1, an exhaustive set of requirements has been compiled. In this section, these requirements are described further.

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2.1 Setup

The tool allows users to draw and edit two distinct store layouts. The drawing of a store layout is done by placing the shelves (horizontal and vertical) in the store. Besides this, it is important that the user can delete, reshape and move the shelves at will. These layouts are converted to the portable bitmap (PBM) file format and they can then be used to run on the simulation model. Besides drawing the store, the users will also be able to change some model parameter settings. These include the number of customers, number of exits, distance between exits, the location of the exits and mask policy's. All these settings can be set for both of the store layouts separately. If all settings are set the user can run the model for those store layouts.

2.2 Visualization

The simulation will simulate normal and infected customers entering and exiting the store based on the Monte Carlo model with an equal probability that a customer is infected for both layouts. When an infected customer is in the store, this infected customer will cough in a probabilistic way. This cough will spread infected air particles through the store, which other customers can run into. Other non-infected customers can run into these infected air particles. Eventually an interference is made on how much non-infected customers run into infected air particles and this corresponds to a certain probability range for being infected (from low to high). The probabilities for both store layouts are equal to ensure a fair comparison for the rest of the process. However, since probabilities are involved, it is possible that the simulations can vary a little from run to run.

After the simulation is completed, the user will be able to analyze the results in depth. To facilitate this the user is given multiple visualizations. The first one allows users to compare ranges of heatmap snapshots from the two layouts. This means that the user can compare multiple snapshots within the same layout as well as between the two different layouts. The user can use the sliders to select a time step range for the snapshots. The user can also decide how many snapshots will be viewed per row. These snapshots contain costumers (normal and infected), exits, shelves and corona aerosol density. The second visualization shows an aggregated heatmap for both layouts. Where the heatmap shows the shelves and the normalized aerosol density over the whole simulation. The third visualization shows multiple graphs. These graphs show the numerical differences between the two layouts. It will contain graphs displaying the number of likely infected customers per layout and the total number of current costumers in the store (infected and uninfected).

The split between two separate store layouts enables the user to quickly and simply compare multiple layouts. This allows the user to quickly analyze multiple possible scenarios for the layout of their own store. Besides this, it also allows user to compare one layout with different parameters. In such a way the validity and effectivity of epidemic prevention measures can be analyzed, such as enforcement of a mask policy or the limiting of costumers in the store. The side by side design of the dashboard makes it quite easy for users to simply compare the two scenarios.

3 System design

3.1 Design

It was decided to use a dashboard for the tool. This interactive visualization tool is build with Dash [1] and is coded in the programming language Python [2]. The tool uses a tabular design where each tab is used for a specific goal. Currently the first tab contains a small user manual that explains the usage and goal of the tool. See figure 2. The second tab is used for generating the store layouts. The third tab is used to change the other store settings as described in section 2.1. The fourth tab is used to run the model simulation. The visualizations of the model outputs are displayed in the last three tabs, where the first two tabs show the heatmaps visualization as described in section 2.2 and the last tab shows the graphs as described in section 3.1.3.

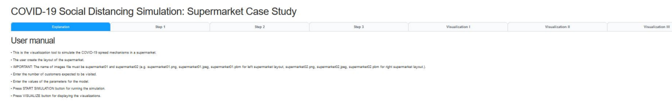

Fig. 2: Dashboard homepage.

3.1.1 Tab 2: Store layout

In this tab, the user can use a drawing tool to create the layouts for the stores. The user can simply click and drag to draw the shelves that form the layout used by the model. The design is such that the two canvases are displayed next to each other. This was done to help the user compare the two layout visually, see figure 3. Besides simply drawing the shelves the user can also interact with the shelves in multiple ways, for example by reshaping, relocating or deleting any of the shelves. When the user is done with editing the shelf layout, the user can save the shelf layout to the Downloads folder by clicking the little camera icon in the top right of the drawing tool interface. After this, the user can click the convert button, which will convert the saved shelf layouts from the Downloads folder and store them in the directory of the project itself. If the user did not create shelf layouts in our drawing tool, the convert button will instead convert files of the specified format in the directory of the project itself. Either way, the converted files are stored in a format that allows for further processing.

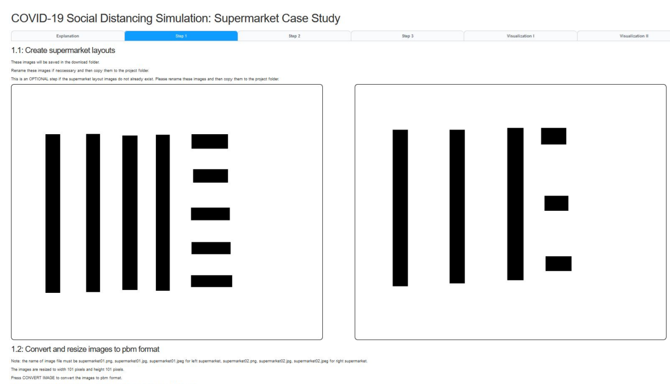

Fig. 3: Canvas for generating store layouts.

3.1.2 Tab 3 and 4: Store settings and running the model

In the third tab, the users can set a number of parameter settings concerning the two store layouts. An image (Figure 4) is included which explains some parameters. The additional setting included by us is the mask policy. Where the user can enforce a mask policy and even chose the type of mask required of costumers. To implement this new model behaviour a lot of research was needed. As first the exact method used to model aerosol emissions, both by cough events and passive, had to be found within the model. Then the literary support needed to be found to support the new behaviour. It was found that the effect of surgical mask compared to N95 masks had a large impact on the number of aerosols released in the case of a cough event. Where the surgical masks reduced the number of aerosols with approximately 5 percent and the N95 mask with approximately 40 percent [7]. For passive aerosol emission there was no noticeable difference between two masks. With 0.06 and 0.07 particles/s [7]. Therefore it was decided to model the passive expulsion the same for both mask policies. The assumption was made that passive expulsion is mostly based on breathing and not on talking. This assumption is based on the fact that costumers in the model come alone to the store and do not interact with other costumers. For the implementation this meant that two variables needed to be changed: *PLUMECONCINC* equals to 40000 and *PLUMECONCCONT* equals to 5. Where *PLUMECONCINC* models the amount of aerosols created by a cough event and *PLUMECONCCONT* models passive aerosols expulsion. These variables where changed to *PLUMECONCINC* equals to 10000 or *PLUMECONCINC* equals to 24000 for surgical and kn95 respectively and to *PLUMECONCCONT* equals to 1.2, see figure 4.

In the fourth tab the user can run the model. At this stage it was decided to give little to no feedback to the user. The only information given to the user at this stage is an indication of the initiation of the model simulation. No real time visualizations are present as there is little to no usable information for the user. The model could take relatively long time to run (e.g. more than 15 minutes for 2000 visited customers). Therefore, all visualizations will be given to the user after the model simulation is completed.

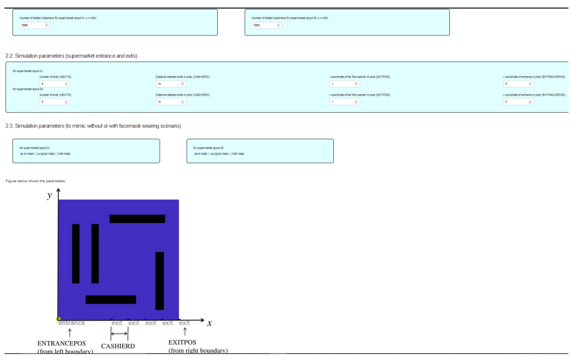

Fig. 4: The settings for the store layouts

3.1.3 Tab 5 to 7: Visualization tools

In the last three tabs show the visualizations of the results. These include heatmap snapshots and graphs. The fifth tab shows a subset of the heatmap snapshots, see fig 5. The main goal of these snapshots is to give the user the ability to analyze the flow of costumers and aerosols over time. By selecting a subset of snapshots for both stores, the user is able to compare the change in aerosol density over time. The sixth tab show as aggregated heatmap for both stores, see fig 6. Here a user can quickly find and compare the hotspots (i.e. aerosol density) with their current layout and different layout. The last tab shows two graphs; where the left graph is used to compare the number of current visited costumers (infected and uninfected) in the store and the right graph show how many customers exposed to the different aerosols levels, see fig 7. Based on the number of inhaled aerosols the costumers are divided over five levels. The first level is the group that has not inhaled any aerosols, which is excluded in the bar chart. The other four levels are the group of customer that have exposed to different level of aerosols. The four different levels are:

i Level 1: number of visited customers exposed to $1.0 - 5.0$ $aerosol/m^3$, low risk

ii Level 2: number of visited customers exposed to $5.0 - 10.0$ $aerosol/m^3$

iii Level 3: number of visited customers exposed to $10.0 - 50.0$ $aerosol/m^3$

iv Level 4: number of visited customers exposed to ≥ 50.0 $aerosol/m^3$

The algorithm for computing the number of customers exposed to different levels are shown in Algorithm 1.

Algorithm 1 Generation of visualizations

procedure COMPUTEACCUMULATEAEROSOLINSTORE
  Initiate a zero aerosol at every coordinate in the store
  Initiate an array of number of customers exposed to aerosol level 1 to 4
  initiate numberCustomerLevel01 equals to 0
  initiate numberCustomerLevel02 equals to 0
  initiate numberCustomerLevel03 equals to 0
  initiate numberCustomerLevel04 equals to 0
  for each customer **do**
    if the customer is already infected and cough **then**
      create a new plume at the coughing coordinate
      add this newly created plume in the cumulative aerosol
      if aerosol level between 1.0 and 5.0 per cubic meter **then**
        numberCustomerLevel01 $\leftarrow$ numberCustomerLevel01 + 1 ▷ record number of customers exposed to aerosol level 1
      end if
      if aerosol level between 5.0 and 10.0 per cubic meter **then**
        numberCustomerLevel02 $\leftarrow$ numberCustomerLevel02 + 1 ▷ record number of customers exposed to aerosol level 2
      end if
      if aerosol level between 10.0 and 50.0 per cubic meter **then**
        numberCustomerLevel03 $\leftarrow$ numberCustomerLevel03 + 1 ▷ record number of customers exposed to aerosol level 3
      end if
      if aerosol level higher than 50.0 per cubic meter **then**
        numberCustomerLevel04 $\leftarrow$ numberCustomerLevel04 + 1 ▷ record number of customers exposed to aerosol level 4
      end if
    end if
  end for
  write the cumulative aerosol to a file, *cumulativeAerosoleFile*
  append numberCustomerLevel01, numberCustomerLevel02, numberCustomerLevel03 and numberCustomerLevel04 into an array *numCustomersLevels*
end procedure
procedure GENERATEACCUMULATEHEATMAPVISUALIZATION(*cumulativeAerosoleFile*)
  create a colormap for plotting the heatmaps
  open and read the *cumulativeAerosoleFile*
  plot the cumulative heatmap by using the Seaborn
end procedure
procedure GENERATENUMBEROFCUSTOMERSLEVELVISUALIZATION(*numCustomersLevels*)
  plot the barchart by using the Seaborn
end procedure

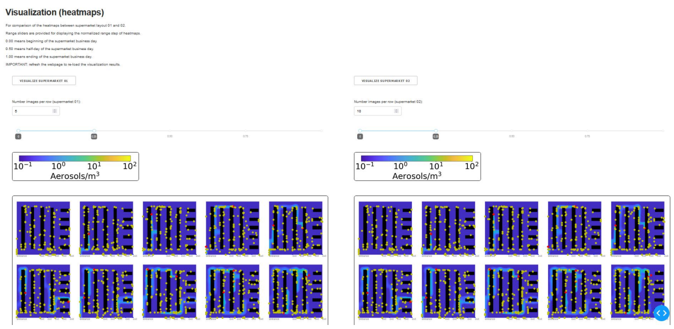

Fig. 5: Heatmap range visualization.

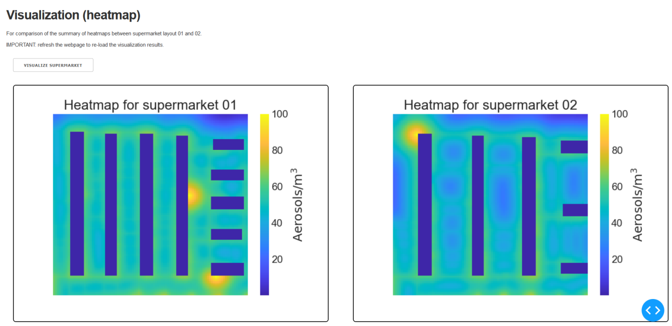

Fig. 6: Cumulative heatmap visualization.

3.2 Design decisions

It was decided to design the tool in a dashboard like fashion. Where ease of use was the main motivator. The goal is to make a tool that can be easily used by store owners to evaluate their store layout to study the effectiveness of epidemic spreading prevention measures.

The dashboard is designed with multiple tabs mainly to increase functionality and user-friendly. While the initial design of the dashboard was being developed there was an explosion of features that all needed to be added somewhere on the dashboard, and having the user to scroll up and down in a single page deteriorate user interaction experience. After that, it was decided to group all functionalities in the dashboard in either the setup or visualization group, and divide these over the tabs that made up the new dashboard to ameliorate user experience.

For the main visualization it was decided to use a heat map as this visualization method gives a lot of insight to the user. This is also the original method used by the model to visualize their findings. It was decided to follow the lead of the authors of the paper and discard height in our visualization. As they found that almost all droplets become aerosols before reaching the ground. Therefore, there is no height used within the model. From this it followed that heatmaps are a meaningful visualization. A 3D visualization was also briefly discussed and subsequently discarded. As there is no height data in the model it would have been necessary to either invent (read guess) or redo the whole model to facilitate a 3D visualization. Besides this, it was also decided that a 3D variation does not add extra information, and instead posses the risk of hiding information from the user.

Python was chosen as main programming language for two reasons: the first is that the original model was written in Python and second that we have experience in Python. Following this, it seemed obvious to also develop the tool in Python.

For the mask settings it was decided to enforce the use of preset values instead of letting users supply their own values. This was done to keep the tool as scientifically sound as possible. The user can only select one of our presets which they are forced to use aerosol expulsion numbers extracted from literature [7].

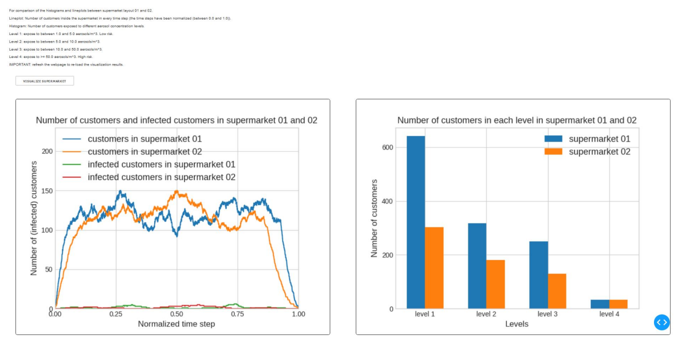

Fig. 7: Line plot (left) and bar chart (right)

4 Results and Evaluation

To validate our tool multiple interesting scenarios have been described below.

4.1 Case 1: wide vs narrow aisles

This scenario shows the impact of the store layout on the spread of aerosols. This can be used by the store owner to find a good layout that minimizes the risk of infection within the store. The example of wide versus narrow aisle scenario is shown in Figure 8. The other model parameters can be found in Table 1. When comparing the two cumulative heatmaps in Figure 9 no huge differences can be seen between the two layouts. In the case of the smaller aisle a overall higher concentration can be seen. This follows from the fact that costumers mainly move near the shelves. If the shelves are further apart there materialises a section where the aerosol density is lower. But as most costumers follow the shelves this also means that most costumers still walk through the high density aerosols near the shelves. When comparing infection numbers we see this as well. When comparing the two layouts in Figure 10 We see a slight decline all over the board. From this we can conclude that wider aisles do not greatly impact the spread of the virus.

Parameter	Supermarket 01	Supermarket 02
number of customers	2000	2000
number of entrance	1	1
number of exits	5	5
facemask type	no facemask	no facemask

Table 1: Parameters setting for case 1.

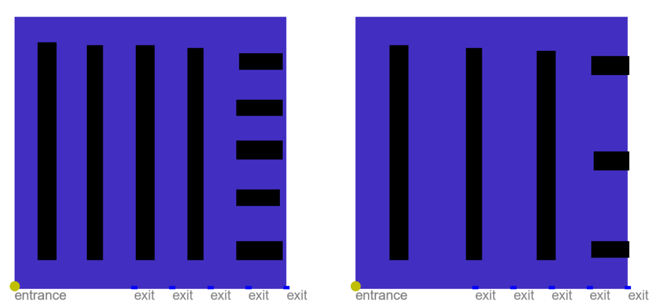

Fig. 8: Supermarket layout with narrow (left) and wider (right) aisles.

4.2 Case 2: facemask vs no facemask policy

This scenario shows the effect the world wide facemask mandates has had on the spread of corona via aerosols. For this scenario the

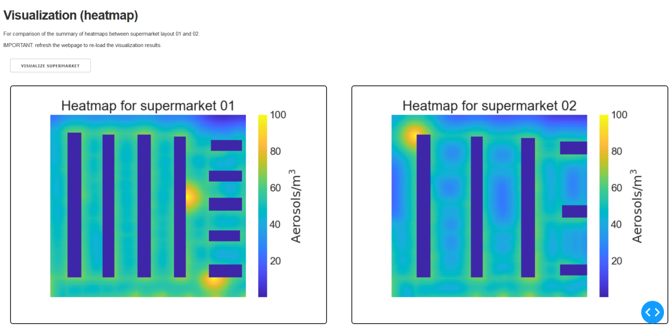

Fig. 9: Cumulative heatmap visualization for supermarket 01 (left) and 02 (right) for case 1.

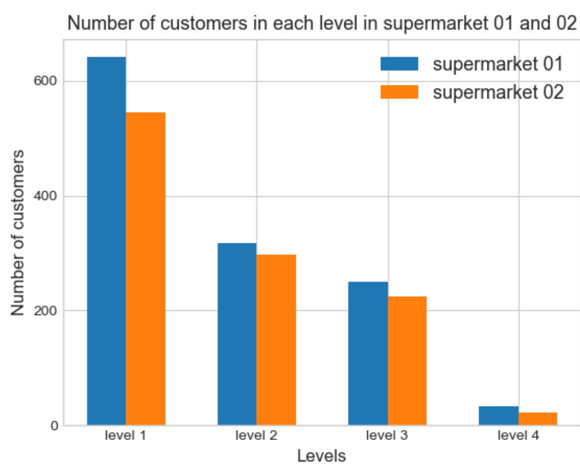

Fig. 10: Number of customers exposed to each aerosol level for supermarket 01 and 02 for case 1.

same store layout and settings where used. The only difference is that one store enforces a mask policy (surgical) while the other does not. The rest of the model parameters can be found in Table 2. When comparing the cumulative heatmaps in Figure 11 in is clear that the overall number of aerosols in the air has dropped dramatically. Near the shelves a drop of approximately 40 percent can be seen. But when looking at the hotspots we also see that a mask policy does not solve bad layouts. As both layouts have hotspots in the same place, reaching dangerous concentrations of aerosols. When comparing the amount of aerosols inhaled by costumers, we do see a very positive result. The number of costumers that inhaled dangerous amounts of aerosols drops dramatically over all levels. The only outlier here being the first group. This follows from the fact that facemask greatly reduce the peaks of aerosol emission but fail to completely eliminate it. This means that places in the store that would have had a very high concentration now simply have a low concentration. This means that more costumers are exposed to lower amounts of aerosols. Besides this group one also contains a lot of costumers that would be in higher groups for the no mask scenario.

Parameter	Supermarket 01	Supermarket 02
number of customers	2000	2000
number of entrance	1	1
number of exits	5	5
facemask type	no facemask	surgical facemask

Table 2: Parameters setting for case 2.

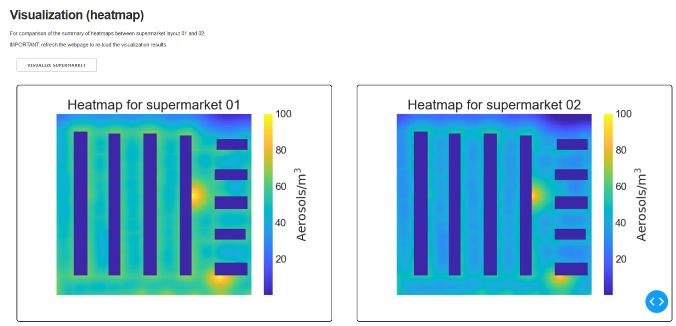

Fig. 11: Cumulative heatmap visualization for supermarket 01 (left) and 02 (right) for case 2.

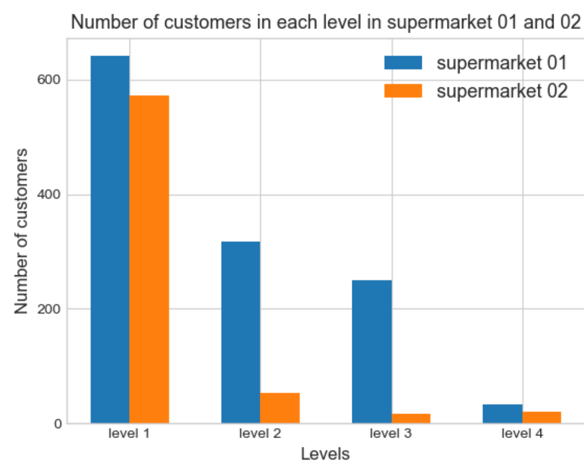

Fig. 12: Number of customers exposed to each aerosol level for supermarket 01 and 02 for case 2.

4.3 Case 3: low number of exits

This scenario is interesting for multiple reasons. Firstly, it was noted that the exits are the largest bottleneck, and therefore spreader, within the model. This is quite natural as the exits are not only the location where costumers leave the store but they also model the registries. So by reducing the number of exits we are effectively modeling the number of cashiers checking out costumers. By running the model with the parameter described in Table 3 below we can see what kind of impact this would have on the spread of aerosols. When looking at the cumulative heatmap (Figure 15) it is clear that reducing the number of exits has horrible effects on the aerosol density. The number of hotspots increases from two to eight. Where most are concentrated around the exits. It is noted that the hotspots spread from the exits towards the entrance. This follows from the fact that this is the direction costumers queue in. This can be seen very well in our other visualization. When selecting a time range halfway through the simulation we can get a clear image of what is going on. When looking at Figure 14 we see a large queue forming at the bottom of the store. This can in turn be matched to the large increase in hotspots at the same location. This is also very noticeable when comparing the aerosol exposure in Figure 16. There is a huge increase in costumers reaching the higher levels of exposure. At the same time, there is a decrease in the costumers in the lower brackets. This follows from the fact that these costumers have simply moved up to the higher risk groups. When considering the case with few exits, a significant number of costumers have been exposed to corona aerosols.

4.4 validity and limitations

Following are the limitations of the usability of the dashboard:

Parameter	Supermarket 01	Supermarket 02
number of customers	2000	2000
number of entrance	1	1
number of exits	5	3
facemask type	no facemask	no facemask

Table 3: Parameters setting for case 3.

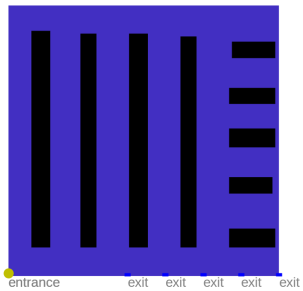

Fig. 13: Supermarket layout with 5 exits (left) and 3 exits (right).

i The entrance and exits can be located only along $y = 0$, i.e. it is not possible for the user to design a supermarket layout which has entrance at southwest and exits at northeast.

ii There is no feedback to the user in the dashboard while the simulation is running, i.e. the user needs to monitor the simulation progress via terminal/command prompt.

iii The dashboard does not display the visualizations automatically when the visualizations are available, i.e. the users are requested to refresh the dashboard for displaying the visualizations to take effect.

Five main questions in section 1 can be answered as followed for showing the validity of the tool:

i What factors are likely to play a crucial role in the spread of the virus?
Based on the simulation results, facemask and number of exits play a crucial role compared to supermarket layout.

ii How many customers can be in the store without significantly increasing the risk of infection?
Although the number of visited customers is not tested in the simulation, however, we can make an educated inference that reducing the number of customers within a supermarket at the same time able to reduce the customers exposed to aerosol level 3 and 4 based on the simulation results.

iii How does the store layout or floor plan influence the virus spread?
The store layout does not influence the virus spread based on the bar chart in Figure 8.

iv How can we visually compare different scenarios?
The cumulative heatmaps and bar chart with different levels are used to visually compare different scenarios. These visualizations are chosen because they are easily understood by the public, policymaker and supermarket owner.

v What is the probability of a customer getting infected after a trip to the store?
Although we do not compute the probability of a customer getting infected after a trip to the store, we are able to draw the conclusion that the probability is drastically reduced if the facemask policy is applied in the supermarket and the probability is increased if the number of exits is not sufficient to handle the customers traffic.

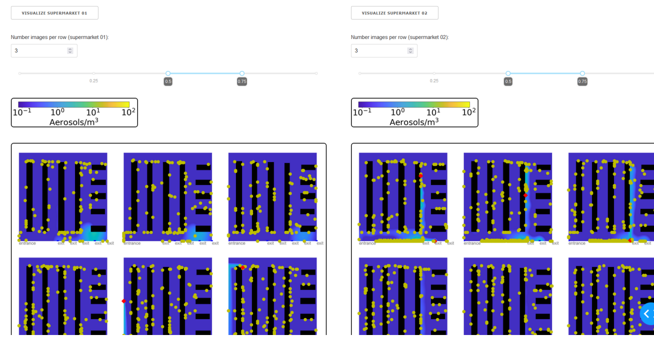

Fig. 14: Heatmap visualizations in the selected snapshot range for supermarket 01 (left) and 02 (right) for case 3.

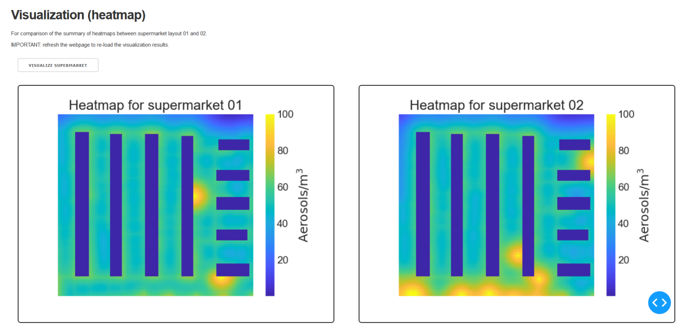

Fig. 15: Cumulative heatmap visualization for supermarket 01 (left) and 02 (right) for case 3.

5 Conclusion and Future Work

The tool created during this project can accurately and effectively help users to minimize the spread of COVID-19 in the supermarket. As can be seen in section 4.4. Store owners can easily ascertain which measures should be taken to minimize the spread of corona aerosols within their stores. Besides this, it is also possible to obtain the general insight into the spread mechanics and prevention measures of infection in general.
For future work, the following improvements in the dashboard can be made to overcome its current limitations:

i The function of setting these parameters can be made through while creating the supermarket layout instead of setting the entrance, number and location of exits through input box.

ii Currently, it is designed that the progress of simulation can only be monitored via terminal/command prompt. Therefore, it is crucial to provide the user real-time simulation progress update on the dashboard to improve the user interface experience.

iii Currently, the user needs to copy and paste the downloaded supermarket layout figures from the Download folder to the project folder and then converted to PBM format. These two steps might be eliminated if the figures can be automatically converted to PBM format and then downloaded directly to the project folder.

iv It would be possible to analysis how ventilation could be implemented to further enhance the versatility of the tool. Before this can be done research is needed into the effects of ventilation on aerosol distribution and dilution.

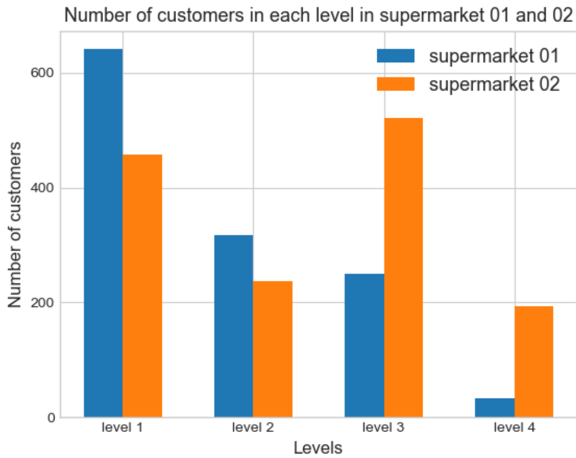

Fig. 16: Number of customers exposed to each aerosol level for supermarket 01 and 02 for case 3.

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