Modelling COVID-19 transmission in supermarkets using an agent-based model

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Introduction

- Early during the pandemic many indoor places where people gather were shut down. Grocery stores were the exception since majority of people get their food from grocery stores.
  Knowing the infection risk in closed spaces where large groups of people is important when trying to reopen business and places of gathering which is especially important now as we are approaching winter.
- In the paper, the authors created an agent based model to simulate the spread of COVID-19 in supermarkets.
- They then model the spread of the disease using synthetic data and discuss various safety measures that could help.

Materials and methods

To understand the model we will discuss its various components

- Store graph
- Agent based model:
  - Customer mobility model
  - Virus transmission model
- Data
- Parameter values

Store Graph

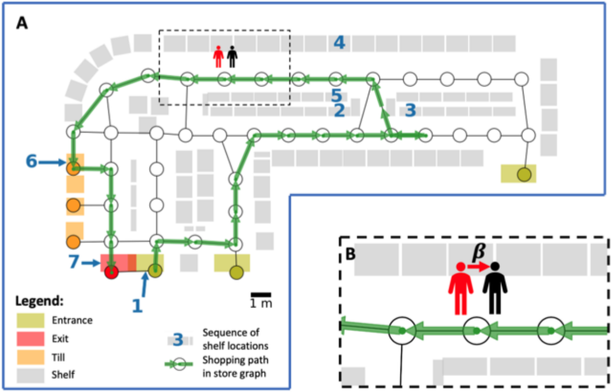


Fig 1. (A) A network representation of a small supermarket/convenience store with an example shopping path (in green). We generate each shopping path from a sequence of shelf locations (in blue), which correspond to the shelves from a customer picks up their items during a visit and the entrance and the tills. **(B)** Virus transmission model. A susceptible customer (in black) becomes infected at rate β whenever they are in the same zone as an infectious customer (in red).

Agent Based Model: Customer Mobility Model

- Customers arrival is modeled using a Poisson process with a constant rate λ.
- Entrance for customers is uniformly chosen, a shopping path is also chosen uniformly at random.
- A shopping path can include the same node multiple times.
- At each node, the length of time, T, a customer stays there is exponentially distributed with mean τ. Waiting time in each node is independent of other nodes.
- When a customer reaches an exit node he stays there T seconds and then removed from the model.
- The store is open H hours, outside of that time frame no customers can be inside.

Agent Based Model: Virus Transmission Model

- Every customer entering the store is infectious with probability p_I, determined by the proportion of infectious people in the store.
- If a person is not infectious, he is susceptible.
- We define the *individual exposure time,* $E_s^{(i)}$*, as the time a susceptible customer* s *is near an infectious person* i*.*
- *The total exposure time* E_s *is the sum of all individual exposure time.*

$$E_s = \sum_i E_s^{(i)}$$

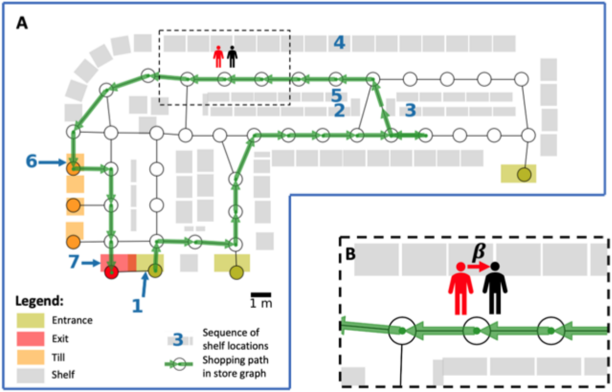
- *Given a transmission parameter* $\beta > 0$*, we determine a susceptible becomes infected at the end of shoppping with probability*

$$\min(\beta E_s, 1)$$

Data

- The store in the model has 80 shelves, 4 tills, 3 entrances and one exit.
- A shopping path,$(s_1, s_2, ..., s_{k-1}, s_k)$, is generated where s_1 and s_k represent an entrance and an exit respectively and $s_2, ..., s_{k-1}$ are random shelves.
- Each location s_i is mapped to its corresponding node v_i and the shortest shopping path containing all nodes is generated.

Data



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Parameter Values

Table 1. Parameter values that we use in our agent-based model

Parameter	**Default value**	**Reference/Assumption**
Arrival rate (λ)	2.55 customer/min	[6]
Mean wait time at each node (τ)	0.2 min	inferred from [10]
Percentage of infectious customers (p_I)	0.11%	[11]
Transmission rate (β)	1.41×10^{-9} per min	inferred from [12] (assuming mean contact duration of 15 mins)
Length of opening hours (H)	14 hours	[8]
Store layout	fixed	Layout of synthetic store

Using UK data, the rest of the parameters were estimated.
The average wait time τ in each node is 0.2 minutes. This was found using pre-COVID19 data so it could be different now. In addition, $p_I = 0.11\%$ and $\beta = 1.41 * 10^{-9}$

Results

Metric	Mean	Standard deviation
Number of customers	2142	48.02
Number of susceptible customers	2139	48.04
Number of infected customers	2.56	1.67
Mean number of customers in store	14.90	0.44
Mean shopping time (in min)	5.94	0.06
Total exposure time (in min)	6.32	4.62
Total exposure time per sus. customer (in min)	0.0030	0.0022
Number of infections	8.91×10^{-9}	6.52×10^{-9}
Chance of infection per sus. customer	4.16×10^{-12}	3.04×10^{-12}

Figure: Simulation Results from 1000 Simulations

Results

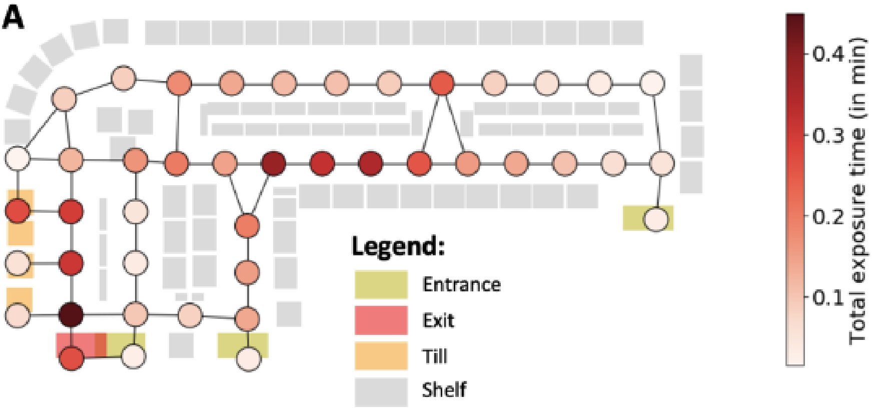

Figure: Total Exposure time per node. Nodes in the centre and near the tills (cashier) of the store show significantly higher amount of exposure time than other.

Varying Customer Arrival Rate

- During the pandemic some stores elected to restrict the rate at which customers enter the store. The model can incorporate this behaviour by varying the arrival rate (λ).

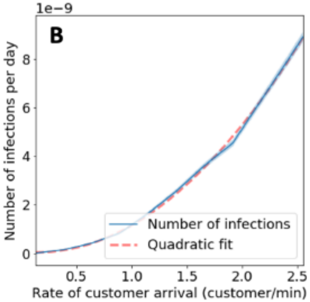

Figure: The Mean Number of Infections (with standard error) in the store across 1000 simulations as a function of the customer arrival time. The mean number of infections scales quadratically with the arrival rate.

Restricting the Maximum Number of Customers in the Store

- Some stores opt to restrict the maximum number of customers in a store, C_{max}.
  - This results in a queue occurring outside the store, where customers will queue up if there is C_{max} or more customers in the store. New customers will only enter the store when the number of customers is below C_{max}.

Restricting the Maximum Number of Customers in the Store

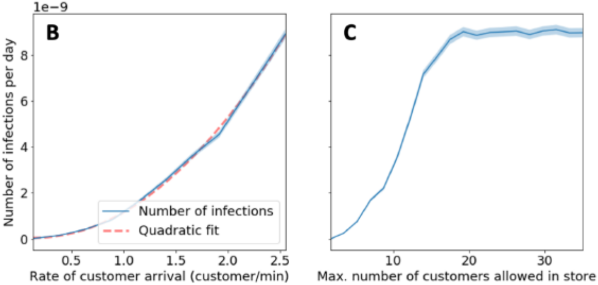

Figure: The Mean Number of Infections as a function of the maximum number C_{max} of customers. The mean number of infections plateaus, as the number of customers typically does not exceed 20 in the simulations.

Face Masks

- The model also analyzes the implementation of a face mask policy, which results in a reduction in the transmission rate.
  - The relative transmission risk reduction rate was estimated to be $RRR = 0.17$.
- This is incorporated by multiplying β with RRR, which reduces the number of infections by the same factor from 8.91×10^{-9} to 1.52×10^{-9}.

One-Way Aisle Layout

- A number of stores have implemented "one-way systems" to assist with the social distancing measures by redistributing the flow of customers.
- The agent-based model can assess this policy implementation by changing the store graph to a directed graph, where some edges are uni-directional.
    - Naturally, the shopping paths have to change, as the current graph may violate the uni-directionality of the one-way layout.

One-Way Aisle Layout

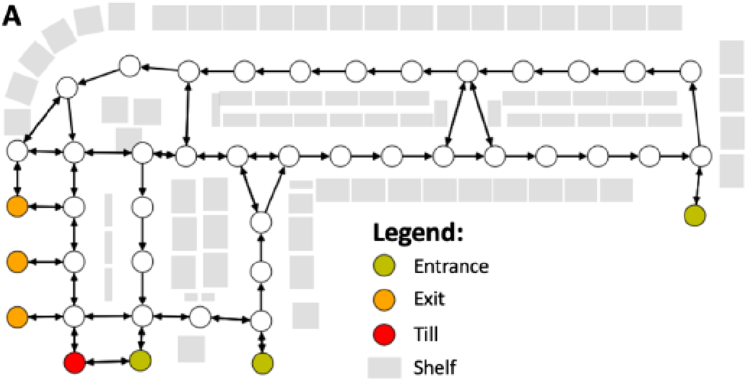

Figure: Store Layout with one-way aisles

One-Way Aisle Layout

- Mathematically, for each path we again consider the node sequence

$$(v_1, \ldots, v_k)$$

from which the path was generated.

  - Reminder, v_1 is the entrance node, v_k is the exit node, and $v_2, \ldots, v_{k-1}$ are locations where customers bought one or more items.

- The corresponding path for the one-way store layout is then the shortest path that visits each of the nodes $v_2, \ldots, v_{k-1}$ in the sequence in the one-way store layout.

One-Way Aisle Layout Results

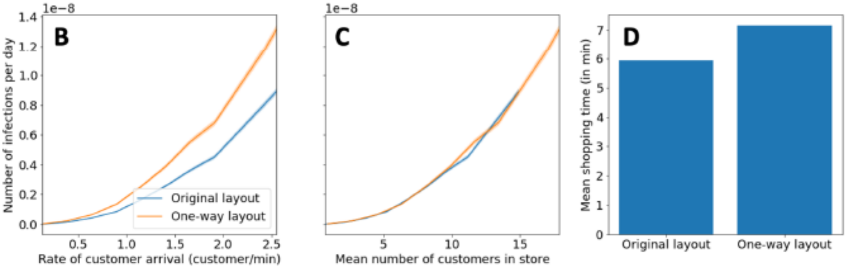

Figure: Number of infections in a store as a function of the customer arrival time and mean number of customers, respectively. The last graph shows the mean customer shopping time.

Limitations

- The customer's path in the model does not depend on the other customers.
- Customers are either in the same zone or not, and thus the precise distance between customers into account is not taken into account.
- It is assumed that the chance of infection is proportional to the exposure time, whereas in reality it may be non-linear (logistic function).
- The model assumes a constant arrival time and random shopping paths that do not change with time. In reality while we expect a time-varying arrival rates and shopping path distributions in reality.
- Large β uncertainty.

References

Yang, Fabian, and Neave O'Clery. "Modelling COVID-19 Transmission in Supermarkets Using an Agent-Based Model." Centre for Advanced Spatial Analysis, 15 Oct. 2020.