

Inspection Model ODD: The following document follows the ODD framework (Grimm et al. 2010) to clearly outline the objectives and implementation of a basic food safety inspection model. Using NetLogo (version 5.0.1)¹, a simulated environment was programmed where consumers, stores, and inspectors interact. One of the goals of the model was to observe the effect of information asymmetry on consumer behaviour. The system-level rules governing these interactions were changed in different versions of the model, allowing for comparisons between the scenarios. Insights from these scenarios can then be used to inform policy discussion.

Purpose: The purpose of this model is to provide insight into the role of information and its influence on the optimal level of inspectors in a food system. To explore this, we compare three search strategies used by inspectors: a random strategy, one where stores can signal to inspectors and consumers that there is a problem, and lastly, an adaptation of the signalling stores scenario that includes false positive and false negative signals.

Entities, state variables and scales:

The entities included in the model are stores, consumers and inspectors. Food products and suppliers are assumed to be embedded within the stores. The tick counter is used to keep track of discrete time steps. Each time the 'go' procedure is called, the tick counter increases by one tick.

State variables:

Patches: Patches have a variable called 'store'; 100 store patches are scattered throughout the model. All other patches represent empty space. Stores are either contaminated or clean – these are represented by red and green in the model. In the scenario that includes possible errors in store signals, store patches also have a variable for the chance of a false positive or false negative signal, which ranges from .01 to .1.

Consumers: Consumer agents are a breed of turtle in NetLogo. There are 2000 of them at the start of the model run.

Table 1: Variable description

Variable name	Description
Range	Consumers use a range of patches within which to search for potential destination stores
Immune system	Consumers have a probability that ranges from 10% to 50% of becoming sick should they land on a contaminated patch
Sick	Consumers become sick if they land on a contaminated store and the random number generated is less than immune-system
Bad store patches	List of stores that have made this consumer sick in the past

¹ NetLogo is available here: <https://ccl.northwestern.edu/netlogo/>

Destination	Changes each time step; set to the most suitable store within the consumer's range that is not a member of bad-store-patches
Heal counter	If a consumer becomes sick, it remains sick for 3 time steps and does not move

Inspectors: Inspectors have a range within which they look for patches to inspect; this range is twice the range of consumers. The number of inspectors in the model has been varied. Firstly, experiments were run using 1-15 inspectors to get a sense of model outcomes. More detailed experiments were then run using 1 inspector, 3 inspectors, and 5 inspectors, respectively.

Minimal spatial element: Consumers and inspectors both have a range within which they can see potential destinations. There are no collectives in the model. Simulations last for 150 time steps (or ticks, in NetLogo); the length of one time step is not specified.

Process Overview and Scheduling:

Once the model is set up, the following processes, described under submodels, are executed in the following order.

- One store per time step is randomly selected and becomes contaminated.
- In the model versions with store closures, stores that have not been visited in 10 time steps close.
- Consumers execute their consume procedure, as follows:
 - Destination-set
 - Consumers evaluate all stores within their range, and choose a store patch that is not on their list of bad-store-patches. If no such store exists, the consumer wanders by randomly setting its heading and moving forward three patches.
 - Eat
 - If the store is contaminated and the random-number generated is less than immune-system, the consumer becomes sick and adds this patch to the list bad-store-patches. The consumer also sets its heal counter to 1.
 - If the consumer is sick, it does not execute the above two procedures, but instead adds 1 to its heal-counter.
- Inspectors test
 - The testing procedure varies depending on the complexity of the model version.
 - In this most basic model, inspectors move randomly to a store within their range. If the store happens to be contaminated, the inspector changes the contaminated variable from 1 back to 0 and changes the store's colour to orange. If the store is not contaminated, the inspector does nothing.
 - In the 'stores signal' scenario, 5 stores per time step are selected to signal; if they are contaminated, they turn pink, which lets consumers know to avoid the store and lets inspectors know to come check it first.

- In the 'stores signal with errors' scenario, 5 stores per time step are selected to signal. If the store is contaminated and a random floating point number is greater than the store's 'signal-error' variable, then the store signals. If the floating point number is smaller, then the store will not signal even though it is contaminated (a false negative). As well, if the selected store is not contaminated, but the random floating point number is less than the store's 'signal-error variable, then the store will signal even though it is not contaminated (a false positive.)
- Consumers that have been sick for three time steps heal.

Since there are no collectives in the model, the order in which each consumer, inspector or patch executes the above is not important.

Design Concepts:

A number of concepts and theories underlie the model's design, and they have been used to influence the variables and the submodels used in the model.

Basic principles: The following basic principles, adapted from the literature on food safety, have been incorporated into the model.

Embedded supply chain: In the model, suppliers and producers are embedded and only stores are explicitly shown in the model. Since consumers only interact with stores and restaurants, and they bear the brunt of responsibility for supplying 'safe' food products, this element greatly simplified the construction of the model. The literature also supports this point: "When major food safety issues arise, both retailers and manufacturers will be affected (if not harmed) by any recall, even if they are not to blame for the problem" (Grievink, Josten and Valk, 2002, p. 481-2, as cited by Havinga 2006).

Inspection system: In the Canadian context, the Canadian Food Inspection Agency is responsible for enforcing policies set by Health Canada that govern the safety of food sold in Canada; the CFIA fulfills this mission by inspecting federally-governed abattoirs and food processing plants. When food safety emergencies occur, the CFIA responds along with Health Canada, provincial ministries, and industry to respond; food recalls are coordinated by CFIA staff. The CFIA is also responsible for enforcing laws on labeling and packaging, regulating products derived from biotechnology (although Health Canada is responsible for assessing the safety of new foods) and certifying exports and initial import inspections of food and agricultural products, among other responsibilities (Government of Canada 2013). Provincial governments are responsible for provincially-licensed abattoirs, which can only sell meat in the province in which they are licensed. Restaurant and food service inspection is quite fragmented, and is generally carried out by municipalities, regional health authorities, or the provincial government, depending on the province (Government of Canada 2014). Although products sold in grocery stores and restaurants have generally been inspected further up the supply chain, these inspections are not represented in the model. The model presented in this paper most closely mirrors the inspection of restaurants and food service outlets.

Immune system: This is one area where there is no real answer in the literature. Although there have been advancements in predictive microbiology, a method used to predictively model pathogen spread, persistence, and death in a food source (Lammerding and Paoli 1997; Walls and Scott 1997), this research does not provide a clear translation of how pathogen loads in a food source affect the actual occurrence of illness.² Certain groups, such as the elderly, young children, pregnant women, and immune-compromised people are more susceptible to foodborne pathogens than others (Gerba, Rose, and Haas 1996), but there is uncertainty as to the actual likelihood of illness from consuming contaminated food products. As such, model runs were completed using an immune system parameter that is heterogeneous and varies throughout the population between .1 and .5.

Consumer avoidance: Previous research conducted by the Food Standards Association in the UK indicates that, if they had concerns about hygiene, up to 70% of respondents would not purchase again from a food service outlet (as cited by Choi, Nelson, and Almanza 2011). As well, focus group research from the UK has indicated that personal experience with food poisoning is an important source of knowledge for changing food safety behaviour, and some quoted participants indicated that getting sick after eating specific products from a supermarket meant that they would never return (Green, Draper, and Dowler 2003, 44). Since the literature did not provide adequate explanation of what factors would influence a consumer to return to a food service outlet where they believed they had contracted an illness, this concept was simplified for use in the model: consumer agents will not return to stores where they have become sick in the past.

Store signals: It is possible for a store to close temporarily and trigger an investigation from inspectors if it realizes that there is a problem with its food. For example, during the 2012 XL Foods *E. coli* outbreak, a Regina restaurant called Flip decided to close its doors when five people reported cases of *E. coli*, and the only common feature with all five cases was that they had recently eaten at Flip (CBC News 2012a). Although the restaurant had recently been inspected and had passed, the owner voluntarily closed the restaurant to keep any other customers from becoming sick while the source of the contamination was determined. This element has been incorporated as a signalling mechanism, where stores change their colour to communicate with inspectors that they should be inspected first and so consumers can avoid that location until the contamination has been rectified.

Store signals with errors: On occasion, stores with a suspected problem may choose to ignore it and not close; there is also the possibility that a store will close unnecessarily. The restaurant Flip, as mentioned above, closed temporarily to undergo thorough testing, which found no *E. coli* present on surfaces or food samples (CBC News 2012b). This has been represented in the model by stores signalling with a small chance of either a false positive or false negative signal. This allows for less than perfect information in signalling, which reduces the efficiency of inspections.

² One such example that was decided by the courts took place in the United States, where FSIS tried to shut down a processing plant that had exceeded Salmonella counts. The plant refused on the basis that the product had come contaminated from the slaughterhouse, and the plant never failed any sanitation tests. A federal judge ruled that FSIS could not withdraw inspection based on Salmonella counts alone: "The appeals court ruling supports arguments of those who say that pathogen testing results should not be a basis for enforcement actions until scientists can determine what constitutes a unsafe level of Salmonella in ground meat" (Rawson and Becker 2004).

Asymmetric information: This principle is informed by Akerlof's (1970) work on asymmetric information in markets. Consumers and inspectors are unable to tell if a store is contaminated prior to landing on it. An interesting application of this theory in future models would be to incorporate signals of quality, such as branding, inspection certificates, or other quality assurance methods.

No consumption while sick: Given the typical symptoms of diarrhea and vomiting that accompany foodborne illness, the assumption that one would stay home and avoid going out to stores or restaurants seems reasonable. This was also implemented for practical modeling reasons, as it prevents a consumer from landing on a contaminated store and becoming sick while already infected from a previous visit.

Emergence: The important results from the model are the overall numbers of sick agents, contaminated stores, inspected stores, and "naïve" agents at the end of the model. Since the changes between model versions are imposed by changes in the rules that agents follow, the results are built in and not the result of emergent behaviour.

Adaptation/learning: Consumers adapt their behaviour by updating the list bad-store-patches. If they have gotten sick from eating at a contaminated store, they add this store to the list and avoid this patch in the future (even if the store has since been inspected and it is no longer contaminated). Consumers also avoid signalling stores.

Objectives: Consumers want to avoid getting sick, and this fits into their adaptive behaviour of avoiding stores that have made them sick in the past. Store patches want to avoid contamination, and if that is not possible, avoid making consumers sick by signalling – although this is imposed. An implicit assumption is that inspectors should inspect efficiently; again, the different inspection strategies are imposed, rather than allowing the agents to choose which they prefer.

Sensing: Inspectors and consumers have the same sensing capabilities: both types of agent can sense when a patch is signalling, and they can tell whether a store is contaminated once they land on it. However, landing on a contaminated store may make consumers sick, but inspectors can reverse the contaminated variable so that the store is safe again. Consumers cannot sense whether a patch has recently been inspected or whether consumers near them are sick.

Interaction: At this stage, neither consumers nor inspectors interact with one another directly. Consumers interact with stores by visiting them (although other consumers may be present there at the same time) and consuming, and inspectors interact with stores.

Stochasticity is used in generating a random number to determine whether or not the consumer will get sick. Also, if consumers complete the 'wander' procedure, they determine a heading randomly and move three patches in that direction. Prediction is not used. There are no collectives, or "aggregations of agents that affect the state or behavior of member agents and are affected by their members" (Railsback and Grimm 2012, 41), in the model.

Observation: The following attributes are tracked using BehaviorSpace at each time step. This output was then analyzed in R (version 2.15.1)

- The number of agents that are sick (indicated by brown agents in the model)
- The number of signalling (pink) stores at any one time
- The number of contaminated (orange) stores that inspectors inspect
- The number of stores that stay contaminated (red)
- The number of “naïve” consumers (those that have never gotten sick over the course of the model run, indicated by yellow agents)

Initialization:

Model runs were executed with 2000 consumers, 100 stores, and 1, 3 or 5 inspectors. The world was set to 33x33, for 1089 total patches, with a centre origin point. The world wraps both horizontally and vertically. Each simulation was run for 150 time steps.

To determine the appropriate number of consumers and stores, simulations were run at various levels of stores and consumers. The actual density of food service outlets is about 1 for every 350 Canadians (Statistics Canada 2006). However, approximating this density in NetLogo would have a prohibitive time cost; running very large simulations in BehaviorSpace is extremely slow. To balance the effects of scaling up with the time cost of running multiple scenarios, 2000 consumers and 100 stores were included in the model.

Consumers: All consumers have immune-system set to between .1 and .5, sick set to 0, heal-counter set to 0, and range set to 5. The lists destination and bad-store-patches are empty. Consumers are scattered randomly throughout the world. In future work, consumers will be made more heterogeneous, but at this point, they are all the same at the start of the model.

Patches: 100 patches are selected, and store is set to 1. All store-patches have the contaminated variable set to 0 at initialization.

Inspectors: All inspectors have a range of 10. They are scattered randomly throughout the world.

Most of these initial values were estimated, as there is little empirical data available. No data was incorporated from other models or external data files.

Submodels:

Consumers: “Healthy” consumers are asked to complete the consume procedure; consumers that are sick must remain on their last destination for 3 time steps. The consume procedure contains two sub-procedures: destination-set and eat. To destination-set, consumers identify which patches within their range are stores that are not on the list bad-store-patches (and are not signalling that they are contaminated, depending on the model version). They then choose one of these destinations from the patch-set and move there. If no patches within their range meet the criteria, the consumer wanders by setting their heading randomly and moving forward three patches. In the eat procedure, the consumer

identifies whether or not the patch they have landed on is contaminated. If it is contaminated and the random number generated is less than the consumer's 'immune-system,' the consumer's sick variable changes to 1 from 0 and the consumer changes its colour to brown, then adds this patch to the its list bad-store-patches. All consumers execute this code in a random order. More than one consumer can land on a store at the same time.

Inspectors: Inspectors are asked to complete the test procedure. Depending on the model version, the inspector is instructed to test any signalling (pink) stores within its range first, since these ones are signalling that they may be contaminated. Otherwise, the inspector chooses a store within its range at random and checks it. When the inspector lands on a store that is contaminated, it changes the store's contaminated variable back to zero and changes the patch colour from red (or pink, if it was signalling) to orange. If the patch is not contaminated, the inspector does nothing.

Patches: Only patches that are stores and belong to the agent-set 'store-patches' will be discussed here. All other patches simply represent empty space. Store patches all start out green to indicate that they are not contaminated, and one store per turn is instructed to change its contaminated variable to 1 from 0 and its colour to red. Agents cannot sense this information prior to landing on the store, unless the store is pink to signal contamination. In versions that incorporate signalling, five patches per time step are instructed to check themselves for contamination. If a selected patch is contaminated, it signals this to consumers and inspectors by changing its colour to pink. In the scenario that allows for signals with errors, the signal procedure incorporates a random floating point number. If the store is contaminated and the random number is less than its 'signal-error' variable, the store will not signal even though it should, and if the patch is not contaminated but the random number is less than its 'signal-error' variable, the store will signal, even though it is clean.

Table 2: Model versions

	Baseline	Signal	Signal with errors
Consumers	Avoid "bad stores"	Avoid "bad stores" & signalling stores	Avoid "bad stores" & signalling stores
Inspectors	Test randomly	Test signalling stores first; if none in range, test randomly	Test signalling stores first; if none in range, test randomly
Patches	Random contamination	Random contamination, up to 5 stores signal per time step	Random contamination, up to 5 stores signal per time step (but signals are uncertain)

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