Conditions Leading Towards a more Robust Food Safety System: The Results of an Agent-Based Social Simulation

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4 authors, including:

Kashif Zia
Sohar University

Dinesh kumar Saini
Manipal University Jaipur

Arshad Muhammad
City University of Science and Information Technology

Conditions Leading Towards a more Robust Food Safety System: The Results of an Agent-Based Social Simulation

Kashif Zia*, Khalifa AlBadi*, Dinesh Kumar Saini* and Arshad Muhammad*
*Faculty of Computing and Information Technology
Sohar University, Sohar, Oman
Email: kzia@soharuni.edu.om

***Abstract*—This paper presents an agent-based model of food safety management. The model proposed by [1] involving consumers, regulators and stores is extended to evaluate the phenomena of "the wisdom of crowds" towards the conditions leading to more dependable system. Through simulation, it is revealed that more vigilance in correction measures ensures a large fraction of interested population available as compared to indifferent attitude, provided that majority of the food providers are vigilant and sensitive to implications of "the wisdom of crowds". Another interesting finding is about self-organizing behavior of the population. It is evidenced that an active society has a capability to self-organize even in the absence of any regulatory compulsion. The implication of these findings is enormous. System components taking a self-organized corrective action resists against system going towards a highly skewed distribution, thus, improving its stability.**

***Index Terms*—Food Safety, Robust System, Agent-Based Model, Social Simulation.**

I. Introduction

Food safety is a growing concern. Scientific advancements provide opportunities towards standardized harvesting and logistics procedures, and safeguarding against contamination in stores. But still a lot needs to be done. This is evident from on going concerns about it in government circles [2], [3] and communities [4], [5]. At the operational level, the regulatory authorities of a country have a major role, which should have an effective, and robust mechanism to deal with modalities of food contamination.

Assessment and correction of food contamination is usually done using food inspection programs in which, stores providing food get central attention. However, it is observed that due to lack of standards, the allocation of inspection resources and agreeing on contamination thresholds has become a challenge [6], [7]. On the other hand, consumers are equally important [7]. The psychological factors representing the perceptions [8], [9] and attitudes [10] of consumers about the food quality is as important as food inspections mechanisms.

Most social systems including food delivery and consumption evolve with time, based on society's needs and restrictions. However, most of these systems are far from perfection due to:

- Diversity of human race, which manifests into a heterogeneous population in terms of resources, and capabilities.
- Inherent lack of balance in human cognition due to selfishness and drawbacks in social and political justice.
- Existence of a gap between social / scientific knowledge and development of an individual, which practically keeps these system in a state often not optimized.
- Flaw in human knowledge and judgment.

Computational Social Science (CSS) is a young discipline, which focus on using computations to solve social problems. It uses the power of abstraction and modeling to mimic real systems in a formal way so that computers can understand and process them. Agent-Based Modeling (ABM) is a front-runner modeling technique used in CSS. In ABM, real objects of interest are modeled as agents having a simplified representation of their characteristics, behaviors, and interactions. Many of individual agents then interact (work together) in a sequential time progression transiting from one state to another representing an evolving society.

The problem of food safety has been tackled with ABM. Naturally, the entities of interest i.e. farms, warehouses, trucks, stores, workers, consumers and regulators, etc. Depending on the problem scale, some entities would be relevant and some are not. For example, food safety from a consumer view point can only focus on the landscape in which a consumer is interacting with the food items. Recently, such a simplistic model is presented by Knowles [1]. The model only have three type of agents; consumers, stores and regulators. The purpose of the model is to investigate the effect of information sharing between stores and regulators on the quality of food consumed by the consumer.

In this paper, we extend Knowles's model [1] to have a more concise significance of the notion of the "wisdom of crowd" towards a more dependable system as a whole. We categorize stores as "vigilant" and "indifferent". The consequence of vigilant stores to take a quick corrective action resists against system going towards a highly skewed distribution of consumers, thus, improving its stability.

The rest of the paper is organized as follow, section II presents related work and motivations, followed by section III presents details of the model. Section IV explains the simulations results, followed by conclusions in section V.

II. Related Work and Motivation

A general overview of applications of modeling and simulation to solve real life problem is presented by Ipek Bozkurt and Jose J. Padilla [11] focused on Epistemological, Ontological, Teleological and Methodological themes. More related to the our research is the work of Mercedes Bledaa and Simon Shackley [12] using agent-based simulation to study formation of risk perceptions; one of the many social theory driven models which have been simulated [13], [14], [15], [16]. Additionally, in systems, many simulation models are proposed i.e., recent model of supply-chain proposed by Houtian Ge, et. al. [17].

An agent-based model simulating an agri-food supply chain is presented in [18]. Another agent-based model to measure the effects of incentive and communication programs towards food safety is proposed by Tim Verwaart and Natalia I. Valeeva [19]. Heterogeneous agents are used representing various modalities of motivations and openness to communications. Jessye Bemley Talley's thesis [20] presents agent-based models to investigate on different aspects of consumer behaviors in the spread of contamination and conditions, in which the public health department must intervene to stop the spread.

A. Knowles's Model of Food Safety Inspections

Only a few authors have used ABM in the domain of food safety. Knowles's Model of Food Safety Inspections [1] is novel, simple and intriguing. Knowles considers two information modalities from stores to regulators. First is when a store starts "signaling" on its own if it is contaminated. In this case, a regulator would promptly visit the store to sterilize it. The second is when contaminated store does not signal and regulators' visit are purely random. In both cases, the consumers, if encountering a contaminated store, register that store in their "bad_stores" list and never visit it again. The adhere to well accepted notion of **the wisdom of crowds** [21].

B. Motivation of the Proposed Model

Knowles does not model the effect of consumers not visiting a store in the store's decision itself. The model keeps a store in contaminated state until it is visited by a regulator. The store does not have to take any action against decreasing number of consumers. We categorize store as "vigilant" and "indifferent", where vigilant stores are responsive to the wisdom of crowds and take effective and timely means to improve the quality of the product. To support this mechanism, we have related a store's contamination with the quality of the product it has. Also, the quality does not abruptly switches between the extremes (contaminated and sterilized), but improves and degrades progressively.

With these enhancements, the model proposed in this paper is able to investigate the effect of vigilance of stores on consumers' health. Our hypothesis is: **More vigilant service providers** – in a situation of decreasing crowd interest due to degradation in the quality of service – **would keep a large fraction of population** – people who do not have prior experience with the service provider – **a potential customer when compared to a service provider who is indifferent**. The consequence of it would be a more fair distribution of customers across competing service providers, thus, improving dependability of the overall system.

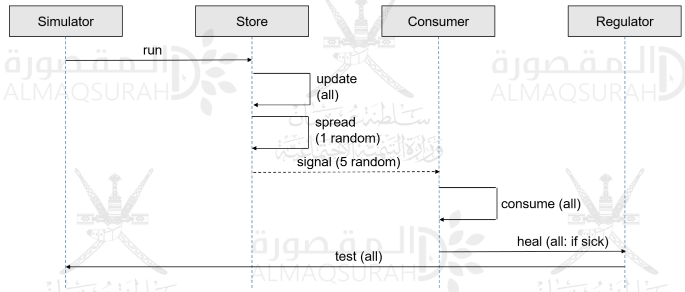

Fig. 1. Sequence Diagram of Simulation Flow.

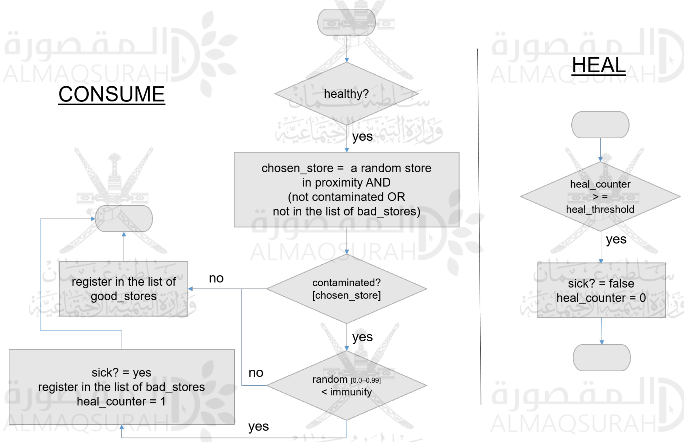

Fig. 2. Process of Food Consumption and Healing by Consumers. No extension of Knowles's Model here.

III. Model

A. Knowles's Model of Food Safety Inspections

The model is based on three agent breeds, (i) consumers, (ii) regulators, and (iii) stores. A consumers executes processes of CONSUME and HEAL, a regulator performs TEST, and a store acts to SPREAD and SIGNAL. A sequence diagram depicting the flow of simulation is shown in Fig. 1, showing four actors. The Simulator is responsible to start a run. Then one of the randomly selected store performed the process of spreading, followed by (optional) signaling by five stores. Then, all consumers follow consume and heal (only those who are sick). At the end, regulators perform test of stores.

A consumer consumes food of a store if she is healthy, while waiting to be healthy again if she is contaminated with the food already taken. For consumption of the food, she chooses a random store in her proximity (defined by her range of accessibility) which is not identified as contaminated by one of the regulators or already listed in bad stores from her prior experience. If the chosen store is not contaminated, she lists it as good store. Otherwise, she is considered as sick if contamination (a random value of plausible health hazard)

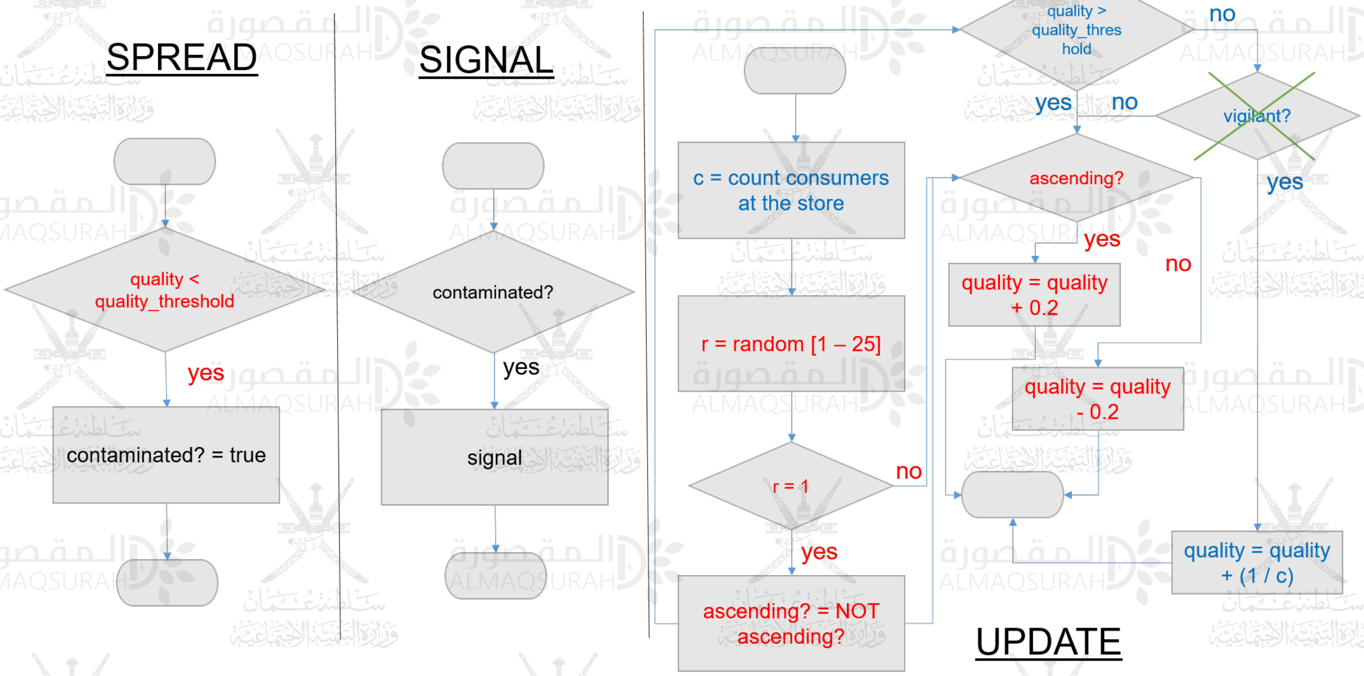

Fig. 3. Process of Spreading and Signaling by Stores. Extensions of Knowles's Model are highlighted with different colors: Red: Case 3, Blue: Case 4, and Green: Case 5.

imposed by the food is more than her immunity, consequently listing the chosen store in the list of bad stores. A consumer also performs healing if it is sick, and her counter of healing is still less than prescribed threshold. Fig. 2 depicts this process.

A store may becomes contaminated at a random instance. It may also decide to signal its state of being contaminated. Fig. 3 depicts this process.

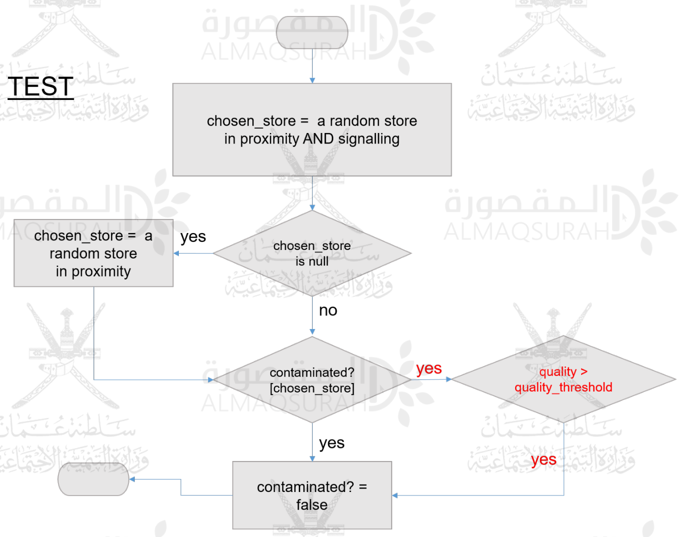

Fig. 4. Process of Testing by Regulators. Extensions of Knowles's Model are highlighted with different colors: Red: Case 3.

A regulator visits a random store in her proximity (defined by her range of accessibility which is more than consumer's) that is already signaling. If no such store exists, it visits any random store in her proximity. As a result of her visit, the store becomes sterilized. Fig. 4 depicts this process.

B. The Proposed Model

The proposed model adds a new process for stores. The UPDATE process enables a progressive quality improvement or degradation of food provided by the store. The progression in one direction (improvement or degradation) happens for a longer period of time before switching from one direction to the other. Evaluation of the quality of the food is then integrated with other processes as well. Such as, the SPREAD of contamination is no more an unconditional decision. A store becomes 'really' contaminated, if quality of the store is less than *quality_threshold* (static value of 0.5). The changes in Knowles's Model are highlighted in Fig. 3. Similar changes are implemented in TEST by regulators in which a store's quality needs to be above threshold to take it as sterilized. The changes in Knowles's Model are highlighted in Fig. 4.

Further, the UPGRADE process is also modeled to reflect the effect of crowd (customers at a particular time) at the store. If "c" is the number of consumers at a store, and the quality of food at the store is less than the threshold, then a "vigilant" would like to have drastic change in the quality, improving it quantitatively proportional to the crowd (say equivalent to reciprocal of "c"). Lastly, the last variation of the model does not differentiate between vigilant and indifferent store, supposing all of them to be anxious and worried about their food quality. These differences are highlighted in Fig. 3.

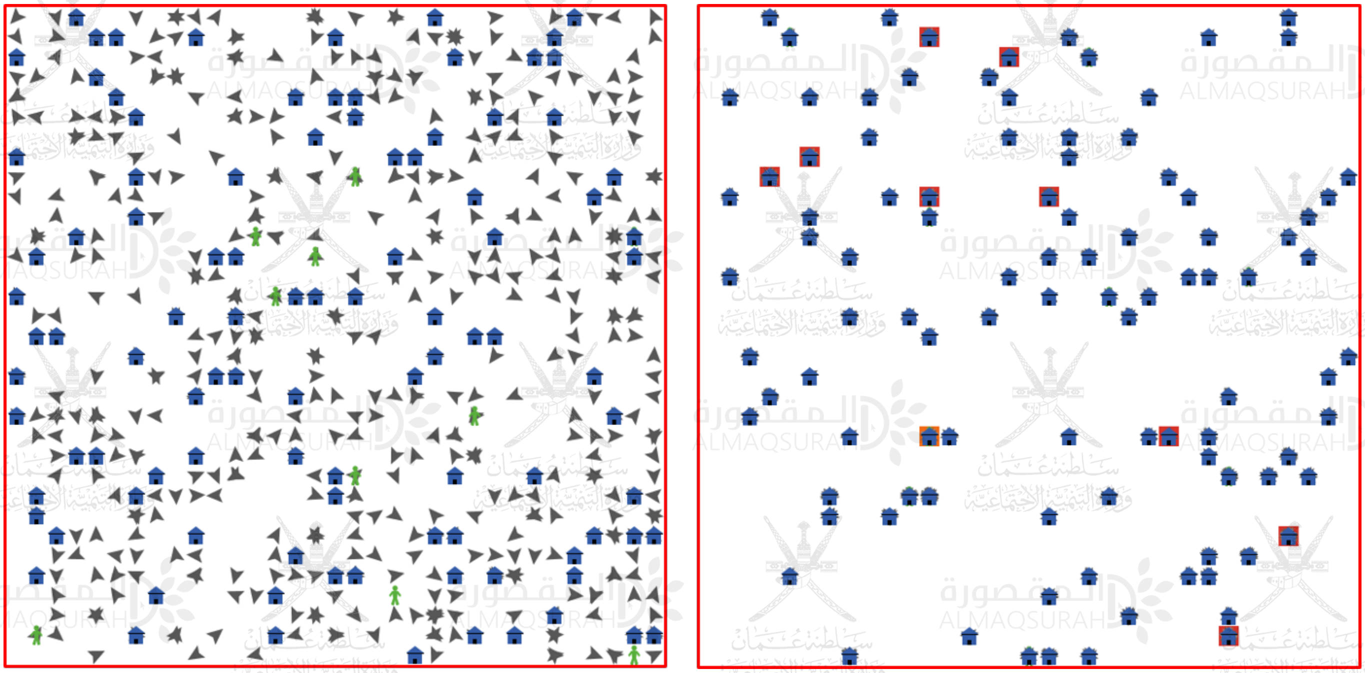

Fig. 5. Case 1: Simulation space consisting of 100 stores (house shape), 10 regulators (person shape) and 500 consumers (regular agent shape). Left view shows the initialization of the simulation. Right view shows the situation at iteration 10. The stores with red background are contaminated, the store with orange background are sterilized; 29 consumers are already sick at this stage.

IV. Simulation and Results

Environment Details: The model is implemented in Netlogo [22]. The simulation space consists of a cellular grid of size 33 x 33. A visualization of agents dispersion on the grid is shown in Fig. 5 for the case 1 and Fig. 6 for the case 4.

Simulation Cases:

1) **Case 1:** Knowles's Model without Signaling.
2) **Case 2:** Knowles's Model with Signaling.
3) **Case 3:** Introduction of UPGRADE process, and the concept of progressive quality improvement or degradation of food.
4) **Case 4:** UPGRADE process with effect of crowd to fine tune progressive quality improvement by vigilant stores.
5) **Case 5:** UPGRADE process with effect of crowd to fine tune progressive quality improvement by all stores.

Each case is run for 100 times to average out the out lairs. Each run executes for 1000 iterations. All cases from case 3 to 5 do not use signaling. Hence, Case 1 is presumably the worst-case and Case 2 the best-case. However, even case 2 does not provide any mechanism of fair distribution of the consumers due to lack of vigilance from stores. Case 3 introduces mechanism of progressive improvement and degradation of quality (by stores). Built on case 3, Case 4 introduces the concept of vigilant stores. Case 5 provides a hypothetically enthusiastic scenario, in which all the stores are vigilant. So, from case 3 to 5, case 5 is presumably the best one.

Simulation Results: The following parameters are user for the analysis:

- **Sick Consumers:** The number of consumers who are sick at each iteration.
- **Contaminated Stores:** The number of stores contaminated at each iteration.
- **Sterilized Stores:** The number of stores sterilized at each iteration.
- **Stores Usage:** Average standard deviation of stores usage, an average value of the whole simulation.

Our assumption about sick consumers and case 5 to be the best case between case 3 to 5 turn out to be true. However, case 5 also outperforms case 2. The reason is that in case 2, signaling alone does not guarantee a regulator in the proximity which could sterilize the store quickly. Whereas, in case 5, the vigilance of (all) stores just sensing a decline in the count of the consumer guarantee a self-correction mechanism which prevent many stores losing a substantial portion of their customers. Hence, at least for these settings of the simulation, we can conclude that an active society has capability of self-organizing without any regulatory compulsions. These results are depicted in the comparison graph shown in Fig. 7.

Also from Fig. 7, it is clear that case 3 is even worse than case 1. The reason is that progressive improvement and degradation in the quality imposes a further restriction on the contaminated stores delaying their status change from contaminated to sterilized. This fact is also evident from the graph shown in Fig. 8. All other cases are comparable with the graph shown in Fig. 7.

The graph shown in Fig. 9 depicts the comparable trends in cases 3 to 5; the more the contaminated stores are the more these become sterilized. However, case 1 and 2 have higher

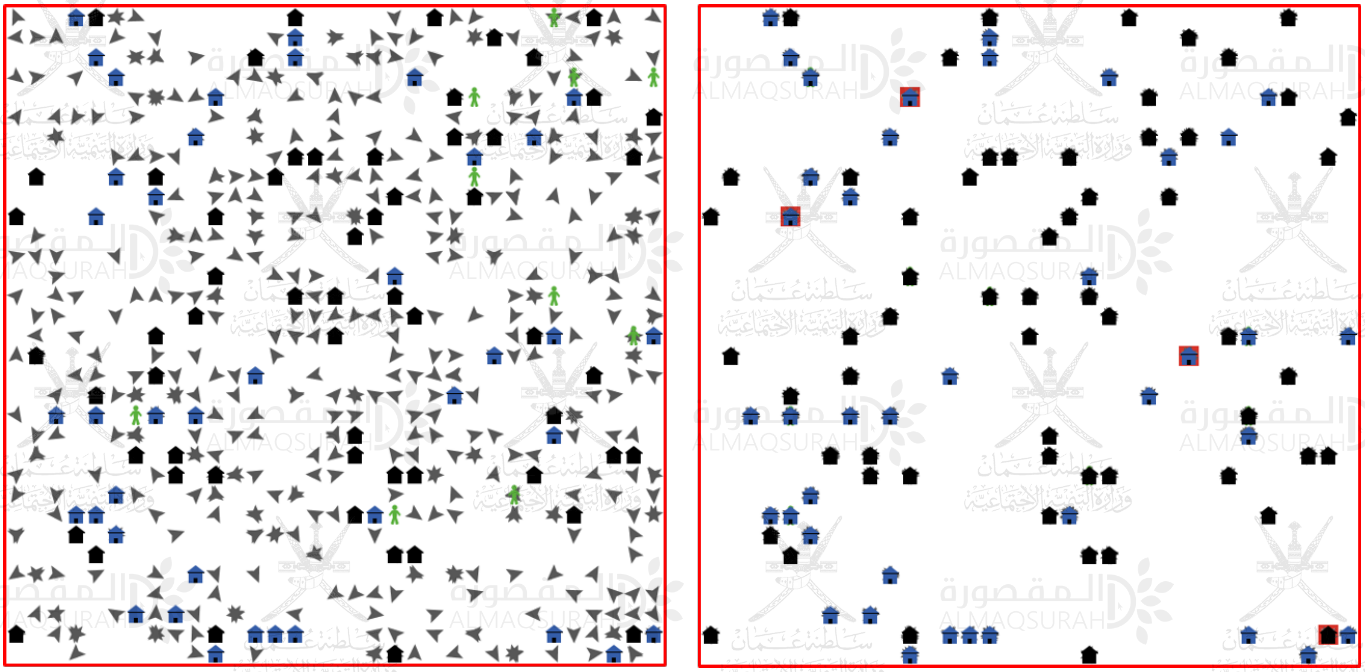

Fig. 6. Case 4: Simulation space consisting of 100 stores (house shape, black stores are vigilant), 10 regulators (person shape) and 500 consumers (regular agent shape). Left view shows the initialization of the simulation. Right view shows the situation at iteration 10. The stores with red background are contaminated; 9 consumers are already sick at this stage.

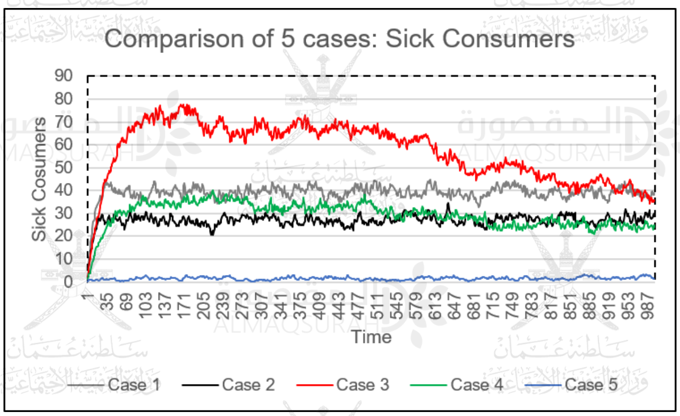

Fig. 7. Simulation Results: Time Series of Sick Consumers, an average of 100 simulation runs.

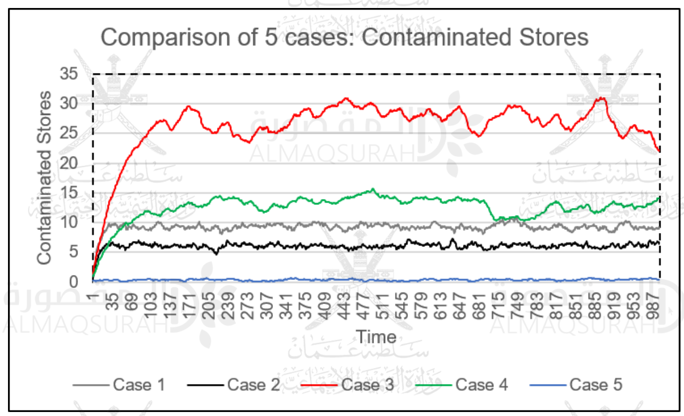

Fig. 8. Simulation Results: Time Series of Contaminated Stores, an average of 100 simulation runs.

values than even these 3 cases, and in terms of contaminated store (Fig. 8), this is not comparable. Again the reason is the restriction imposed by progressive quality update, which inhibits the stores an abrupt status change from contaminated to sterilized.

Lastly, the fairness in stores usage is represented by average standard deviation of consumers presence at the stores. As shown in the graph in Fig. 10, the highest value comes against case 5. The standard deviation is stores usage represents the fairness in consumers presence in the stores. This means that the hypothesis that "more vigilance in correction measures ensures a large fraction of interested population available as compared to indifferent attitude" is verified. This may lead to increase in dependability and robustness of the system. However, this hypothesis not true for case 4, which turns out be the least. This means that the hypothesis should be rephrased as: "more vigilance in correction measures ensures a large fraction of interested population available as compared to indifferent attitude, provided that majority of the service providers are vigilant and sensitive to implications of "the wisdom of the crowds".

V. Conclusion

An agent-based model of food safety management is presented in the paper. The model extends a simple model of food safety [1] involving consumers, regulators and stores. The

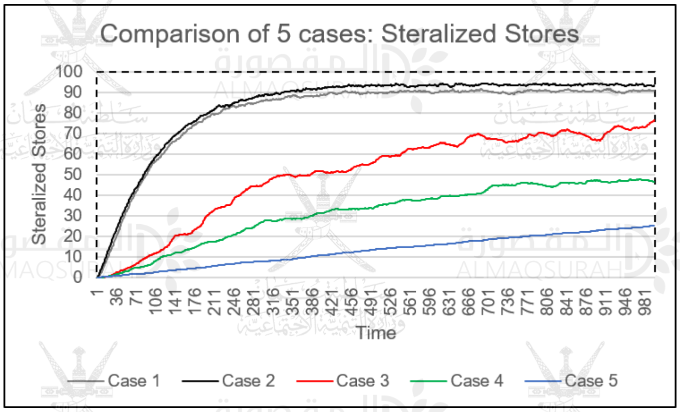

Fig. 9. Simulation Results: Time Series of Sterilized Stores, an average of 100 simulation runs.

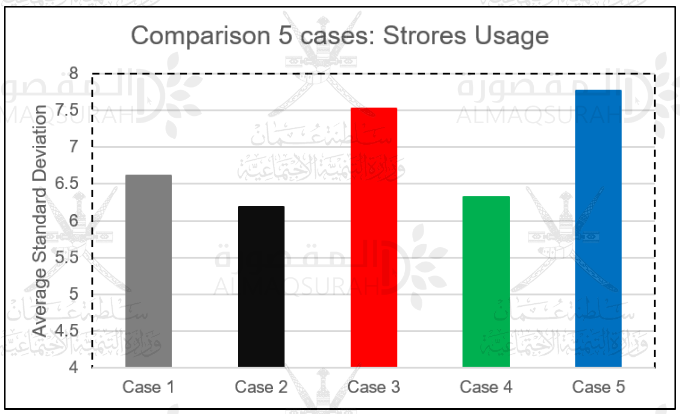

Fig. 10. Simulation Results: Time Series of Stores Usage, an average standard deviation of 100 simulation runs.

notion of the "the wisdom of crowds" was used to analyze the modeling components and the simulation results. Consequently, the situations leading towards a more dependable system were identified. In particular, the following hypothesis was verified: more vigilance in correction measures ensures a large fraction of interested population available as compared to indifferent attitude, provided that majority of the food providers are vigilant and sensitive to implications of "the wisdom of the crowds". Another interesting and not intended outcome was the observation of self-organizing behavior of the population without any regulatory authority. A self-organized corrective corrective action resists against system going towards a highly skewed distribution, thus, improving its stability.

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