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Assessing Consumer Compliance During Milk Contamination Events

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Abstract: Pathogens such as Salmonella, E. Coli, Listeria, and Campylobacter create numerous food contamination events in the United States throughout the year. Raw Milk when not produced properly can contain these pathogens and infect customers when consumed. Cross contamination in the milk supply chain can increase the spread of pathogens and food borne illnesses. Simulation models are developed to determine the cause of food contamination events and analyze the flow of information when a contamination event occurs. An agent-based model will be produced to track and analyze how consumers move through the susceptible, exposed, infectious and recovery model. A system dynamic model will be used to analyze the production processes of milk to trace contamination occurrences throughout the supply chain process. A survey will be conducted which will use consumer behavior to assess compliance and risk communication strategies during a food contamination event. This paper recommends the usage of the data found from this experiment to improve the milk production process, decrease the number of milk related food contamination events, and enhance the knowledge of consumers with relation to food contamination.

Keywords: Milk, Food Contamination, Agent Based, System Dynamic, Simulation

1. Introduction

The presence of pathogens in the milk production industry is a growing problem for milk food safety. According to the CDC (2017), the percentage associated with raw milk increased from 2% from 2007 through 2009 to 5% from 2010 through 2012. In the United States there have been multiple food contamination events from milk linked to the following pathogens: Salmonella, E. Coli, Listeria, and Campylobacter (CDC, 2017). Raw milk poses the greatest risk because it has not been pasteurized to eliminate catastrophic bacteria agents. These previous pathogens listed were consumed by customers which resulted in food illnesses around the country. Symptoms of raw milk poisoning include diarrhea, stomach cramping, and emesis. In extreme cases of raw milk poisoning, consumers have faced life threatening illnesses such as Guillain-Barré syndrome, causing kidney failure, paralysis, stroke or more seriously death. According to the CDC from 1993 through 2012, 127 outbreaks reported were linked to raw milk. There were 1,909 illnesses and out of those reported 144 needed hospitalizations. Majority of the illnesses resulted from Campylobacter, E. coli, and Salmonella. The main demographic affected by these outbreaks were children under the age of 5, they accounted for 59% of the outbreaks between the years of 2007 and 2012. Another 38% of the salmonella cases from the raw milk outbreaks were children between the ages of 1 and 4 (CDC, 2017). It has also been stated that college students have a greater risk of being affected by food contamination events when it comes to risky food safety behaviors in dairy products because dairy is a prime source in a college student's diet. (Booth et al., 2013) In most of the cases found, cross contamination occurred during the production process from contact between humans and ingredients. Raw milk could also be contaminated through contact with animal feces, mastitis, cow diseases, bacteria on the skin of animals or humans, insects, rodents, vermin, unsanitary conditions or cross contamination between workers and their dirty clothes.

Milk is high in food value and has a lot of benefits from its consumption. It has a wide variety of nutrients including calcium, potassium, and vitamin D which are all essential for growth of the human body (Jeločnik, 2019). Milk can be extracted from a variety of animals which can include cow, goat, sheep, et. Contamination of milk can be caused by factors in the food chain consisting of food handling, storing and processing. The milk industry must offer high-quality and safe milk to prevent food-borne diseases that could spread in the population (Velazquez-Ordonez, 2019). The safety and prevention of contamination of milk is a very important topic since it is used for daily nutrition and processed into many other foods.

The objectives of this research include using consumer behavior to assess compliance during a food contamination event, assess risk communication strategies during a food contamination event, and create a simulation model for assessing food supply chain risk communication and consumer behavior during food contamination events. The simulation models that we will use to assess will be an agent-based model and a system dynamic model.

2. Literature Review

Agent Based Models simulate the flow of information between decision-making agents. Füzesi, I., Csordas, A., Reuf, S., & Felföldi, J (2020) discuss the use of food traceability systems to provide food history information. The AnyLogic software was used to develop combined agent-based simulation and Discrete event-driven model to track and assess the necessity of a new food tracking system for consumers. Mokhtari and Doren (2019) discussed the use of an agent-based modeling system to explain the complexity of the spread of bacteria in food facilities. This system will provide options to mitigate the number of pathogens that could potentially travel through a facility. The model focused in on the actions of food handlers and the activities and decisions made day-to-day regarding food and hygiene. A sample case study was created to test the effectiveness of the model and show how different strategies or choices reduce contamination. The main pathogen being tracked in this process was Listeria monocytogenes. Wiltshire, S. (2018) discusses the use of agent-based modeling to analyze the network of hog production and track the rate and process of diseases. Armstrong and Chaturvedi (2014) discuss the use of agent-based simulation to understand the interdependence of the food supply chain in Securing the Food Supply Chain. It describes the Food Defense Simulation (FDS) which is based on the Reference World Information and Simulation Environment (RWISE) platform. This platform represents the complex dynamics of the post-harvest supply chain that includes ingredient suppliers, processors, distributors, retailers, and consumers. FDS can be used to explore and strategize different strategies to secure food from bioterrorist attacks. These tools give perspective on the many different scenarios bioterrorists attacks can be reduced.

System Dynamic models can be used for long-term and strategic planning. Lagarda-Leyva et al. (2019) discuss how system dynamic modeling and reverse logistics can be used to study the management of plastic waste in agricultural systems. Espino and Bellotindos (2020) discuss the use of system dynamic modeling in the analysis of long-term sufficiency in the poultry sector in the Philippines. This is critical in food security and sufficiency since this analysis can be conducted on different areas of food production. Oliva & Revetria (2008) discuss the use of a system dynamic model to analyze and validate a current cold chain management system to eliminate the spread of food borne diseases. The increase of these food contamination events have been linked to four main parts of the warehouse: Storage, processing, distribution and packaging. This study specializes in looking at raw meat products being prepared and transferred within a facility. The cold chain management system is a key process that was originally made to decrease the spread of diseases and maintain the quality of the meat products. The system dynamic model discussed in this article was created to enhance the quality of meat and limit the spread of contaminants.

3. Methodology

3.1 Models

For this project we consider a food supply chain that consists of the following structure: producer, processor, distributor, and eventually goes to the end consumer. A food contamination event will occur and evolve based on consumer behavior (i.e. purchasing and consumption). Food contamination will happen at the production level. We solve this problem using an agent-based model and system dynamic model. This will assess the consumer contributions and understanding of different contamination events that occur in milk.

Figure 1 shows how the agent-based simulation will be based on the SEIR model. When a consumer flows through the SEIR model different communication strategies will be implemented in the model. When the company is made aware of an exposure, the company will acknowledge the exposure and communicate it through an announcement. When the company is made aware of an infected consumer this is when risk communication will be implemented. The company must identify the hazard, assess the risk, develop the policy, communicate the policy, and lastly evaluate the policy. During the communication policy phase, there could be two forms of communication, word of mouth or social media. When a consumer is fully recovered, they will be able to communicate their experiences to the public. This communication will also be either word of mouth or social media.

Figure 2 shows the complete production cycle of milk, from the farm to the shelf at the store. Within a few of these processes of production, there are some areas that we wanted to focus on, which include transport, and distribution. There are three separate production chains to separate the pathogens that we used. Within harvesting, the assumption is made that the use a milking machine to harvest the milk. Storing and transporting the harvested milk is a focus point since milk needs to be stored at a certain temperature and housed in proper packaging to stay fresh. In processing, pasteurization is the processing method of choice being that it is more common. This is where contamination can happen as well. These focus points give us an idea on how these processes can be improved to limit contamination. This simulation's purpose is to run three different production chains simultaneously with 3 different pathogens that are common in raw milk contamination. This can assist producers in showing the amounts of contaminated milk that they could be producing

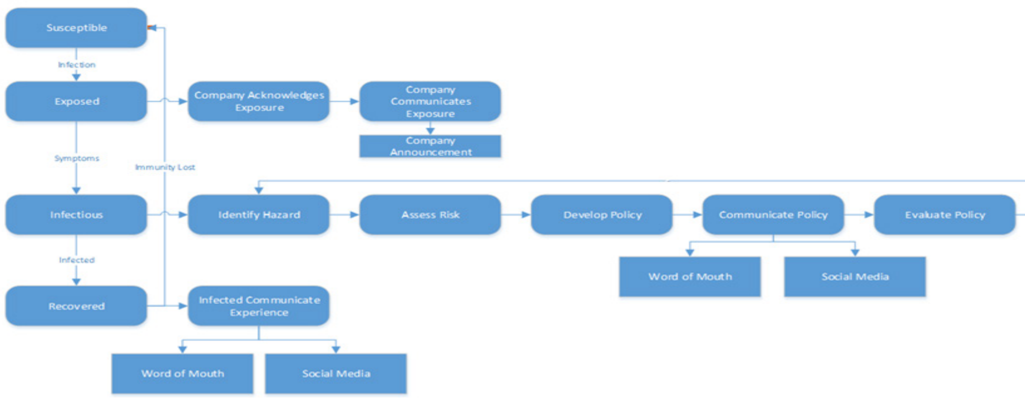

Figure 1. Agent Based Model Flow Diagram

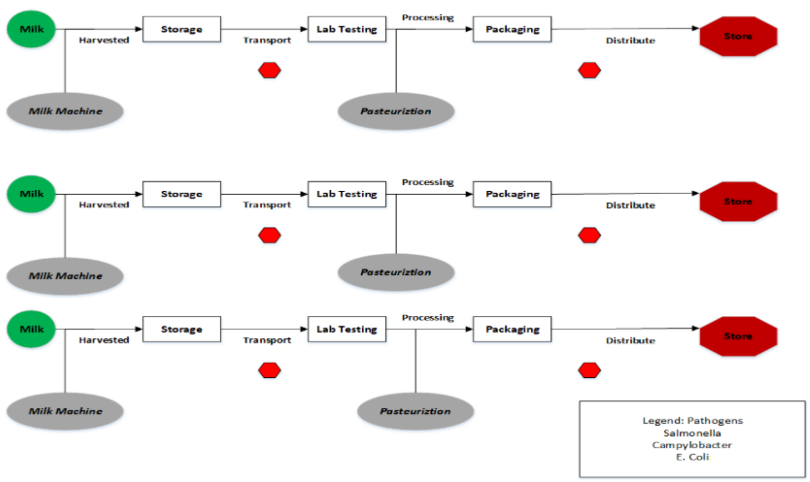

Figure 2. System Dynamic Model Flow Diagram

3.2 Case Study Description

The agent-based model experiment entails a comparison between the SEIR model without the risk communication versus the SEIR model that included the risk communication. This model an initial number of 1,000 consumers, all SEIR rates, and salmonella was used as the main pathogen. The time window that data was collected was for 30 days. The rates for risk communication were established based on data from Forbes (Martin, 2018).

A table of parameters according to the CDC can be found below (Table 1). All infected and recovery rates were based on a triangular distribution using the min, average and maximum values.

Table 1. Agent Based Model Parameters

Parameter	Rate	Unit
Exposed Rates (All Pathogens)	0.01	Consumers/Day
Salmonella Infected Rate	Triangular (6, 36, 72)	Hours
Salmonella Recovery Rate	Triangular (4, 6, 7)	Days
Campylobacter Infected Rate	Triangular (48, 72, 120)	Hours
Campylobacter Recovery Rate	Triangular (6, 7, 10)	Days
E. Coli Infected Rate	Triangular (24, 120, 168)	Hours
E. Coli Recovery Rate	Triangular (5, 6, 7)	Days
Social Media Announcement Rate	0.55	Consumers/Day
Social Media Policy Rate	0.55	Consumers/Day
Social Media Experience Rate	0.30	Consumers/Day
Word of Mouth Announcement Rate	0.16	Consumers/Day
Word of Mouth Policy Rate	0.16	Consumers/Day
Word of Mouth Experience Rate	0.15	Consumers/Day

The system dynamic model experiment involves conducting a sensitivity analysis for a few different production scenarios. For a general scenario, the milk flows at a rate of 1000 units. Once the milk is transported to the lab, the assumption is made that during this transfer, some units of milk are exposed to pathogens in this state. This area is labeled by the parameter, Area1, where the percentage of these contaminations can be adjusted as info is received. Table 2 shows the parameters for the system dynamic model.

Table 2. System Dynamic Parameters

Parameter:	Rate:	Unit:
Salmonella	0.38	%/cycle
Campylobacter	0.15	%/cycle
E.Coli	0.28	%/cycle
Area (1-6)	0-1000	units/cycle
UnharmedMilk	100%	%
UnharmedMilk1	100%	%
UnharmedMilk2	100%	%

$$U_m * (S_c * A_i) * A_i \tag{1}$$

$$U_m * (E_c * A_j) * A_j \tag{2}$$

$$U_m * (C_c * A_k) * A_k \tag{3}$$

where $i = 1,2;\ j = 3,4;\ k = 5,6$

U_m = unharmed milk; S_c = Salmonella; E_c = E. Coli; C_c = Campylobacter; A_{ijk} = Areas

4. Results

The data collection shows that the two models are similar when comparing the SEIR aspect. Figure 3 shows the results specifically for the SEIR model with communication. The data shows that there is an average of 275 total people who entered the simulation and changed states whether there were risk communication strategies implemented or not. The data also showed that there was an average of 215 consumers who were able to be fully recovered with and without the implementation of the risk communication strategies. The risk communication strategies cannot actively change how a consumer flows through the

SEIR model when they have already entered the system. The risk communication strategies are made to prevent someone from entering the SEIR model or for the number of susceptible consumers to decrease in a second iteration. Therefore, the values are the same when both simulations complete a 30-day period and the SEIR values and analyzed. There is an expectation of the agent-based model with the communication strategies to have lower susceptible rates if a loop was to be implemented.

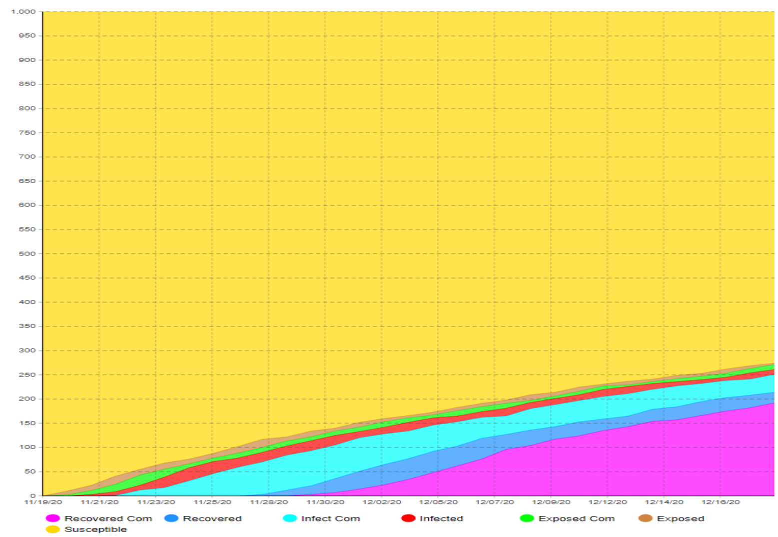

Figure 3. SEIR Data with Communication

The results in Figure 4 shows the contamination risk from both Salmonella and E. Coli. The results for salmonella show that out of 1000 units being produced, only 384 units went through the production cycle unharmed. Since the contamination rate for Salmonella was high, this was expected. It was interesting to note that there were 380 possible contaminations in the first observed area, and about 239 in the second. The E. Coli test showed about 516 units of milk were produced unharmed, while the remaining units were at risk of contamination. Figure 4 show the data for contaminated products in Area 3 and Area 4 to be 380 and about 204 respectively.

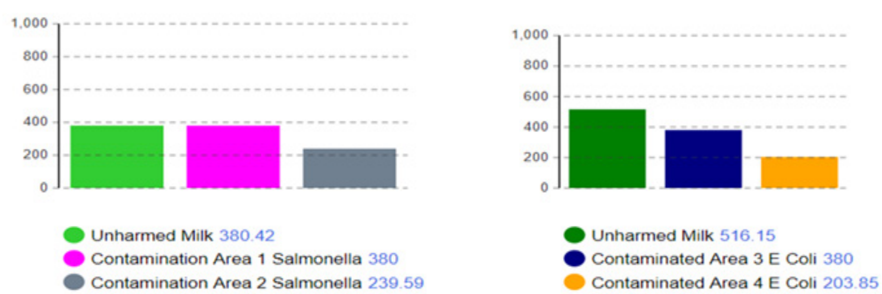

Figure 4. Salmonella and E.Coli

5. Conclusion

In conclusion, the agent-based model was properly developed and actively showed the significance of risk communication strategies in the exposed and infected states of the SEIR model. When a consumer views a risk communication strategy during these two states, they are more likely to comply to the statements and less likely to become susceptible a second iteration. The agent-based model also displayed the importance of using social media as the prime communication source. We would recommend social media to be the communication source for risk communication strategies because it will reach more consumers at a faster rate.

The system dynamic model was developed to function as an analysis tool when contamination events are occurring. This can assist with risk mitigation and communication at the production level. If the production of contaminated milk products is mitigated, there would be a positive impact, where there are less contamination events and less consumers contracting food-borne illnesses. This simulation can also be expanded in many different aspects to improve the analysis of the production cycle and create better strategies when contamination is detected.

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