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RFID-generated traceability for contaminated product recall in perishable food supply networks

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ABSTRACT

As perishable food supply networks become more complex, incidents of contamination in these supply networks have become fairly common. Added to this complexity is the fact that there have been long delays in identifying the contamination source in several such incidents. Even when the contamination source was identified, there have been cases where the ultimate destination of all contaminated products were not known with complete certainty due, in part, to dispersion in these supply networks. We study the recall dynamics in a three-stage perishable food supply network through three different visibility levels in the presence of contamination. Specifically, we consider allocation of liability among the different players in the perishable supply network based on the accuracy with which the contamination source is identified. We illustrate the significance of finer levels of granularity both upstream and downstream as well as determine appropriate visibility levels and recall policies.

1. Introduction

The number of food contamination incidents and their resulting consequences in terms of the health of the population as well as associated monetary and other costs attest to their significance. The sheer volume as well as the number of players at each level in these supply networks expose them to vulnerabilities. Complicating this is the fact that some of the end-products in these supply networks go through various amounts of dispersion that render it difficult to identify and isolate the contamination source. Here, dispersion, as the term suggests, refers to the complex manner in which ingredients or raw materials get mixed to form the next level product, which then can be mixed further for the next level product, and so on. To err on the safe side, it is not uncommon to shut down the entire supply network until the contamination source is identified. A deleterious side-effect of this is the unnecessary disruption that occurs in parts of the supply network that are unaffected by contamination.

Food contamination occurs in several different forms, due to chemical contamination or microbial spoilage, among which the Bovine Spongiform Encephalopathy (BSE), salmonella and the *Escherichia coli* (*E. coli*) are well-known. There have been numerous food-borne illness outbreaks, the deadliest of which include the 1985 California Listeriosis outbreak through cheese, the 2011 German *E. coli* outbreak through bean sprouts, the 2011 Colorado Listeriosis outbreak through cantaloupes from Jensen Farms, the 1985 Midwest United States salmonellosis outbreak through milk from Hillfarm Dairy in Illinois, the 1995 Washington State *E. coli* outbreak due to undercooked hamburgers at Jack-in-the-Box stores, the 2003 hepatitis A outbreak from tainted green onions at a restaurant in Monaca, Pennsylvania, the 2005 South Wales *E. coli* outbreak due to cross-contamination at a vacuum packing machine used to package both raw and cooked meat without being properly cleaned between batches, among others. When a food safety outbreak occurs, a series of actions are generally taken that include identifying the cause (biological, chemical) and source of contamination and subsequently recalling the contaminated products.

Among the recent food recall incidents, a well-known example is the 2008 recall of peanut butter in the USA due to the presence of salmonella. It was the largest product recall ever in the history of the country, involving more than 200 food manufacturers downstream in the supply chain resulting in the recall of more than 2100 products [18]. The difficulty and the required investment for establishing a successful brand in the food industry combined with the strong sensitivity of consumers toward such outbreaks and the strict national and international regulations for fast and firm reaction has often led to unbearable financial losses especially for food manufacturers after an outbreak. While food safety crises can develop at different stages in a supply chain, the lack of traceable and transparent information flow within supply chains often makes it very difficult to identify the actual source of

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Nomenclature

s_i	supplier i ($i = 1 \cdots s$)
m_j	manufacturer j ($j = 1 \cdots m$)
r_k	retailer k ($k = 1 \cdots r$)
P_{s_i}	probability of contamination at Supplier$_i$
P_{m_j}	probability of contamination at Manufacturer$_j$
I, B, S	item, batch, and SKU levels respectively
x	$\in\{I,B,S\}$; Minimum visibility at all nodes in a given (supplier or manufacturer) level
$T_{s_i m_j}(x)$	traceability of items from supplier s_i to manufacturer m_j
$T_{m_j r_k}(x)$	traceability of items from manufacturer m_j to retailer r_k
$T_{s_i}(x)$	$\forall m_j$, $\min\{T_{s_i m_j}(x)\}$
$T_{m_j}(x)$	$\forall r_k$, $\min\{T_{m_j r_k}(x)\}$
$T_{m_c}(x)$	$\forall r_k$, $\min\{T_{m_c r_k}(x)\}$, where m_c is the (manufacturer) contamination site
$p_{s_i m_j}$	fraction of items (among those sent from suppliers to manufacturers) sent from s_i to m_j
$p_{m_j r_k}$	fraction of items (among those sent from manufacturers to retailers) sent from m_j to r_k
q_t	quality of item at time t
q_o	quality of item when it leaves the supplier facility
q_m	quality of item when it arrives at the manufacturer facility
q_r	quality of item when it arrives at the retailer facility
v	value-added to the item at manufacturer level
d	disposal cost of a contaminated item
λ_{sm}	food quality decay parameter between supplier and manufacturer
λ_{mr}	food quality decay parameter between manufacturer and retailer
t_{sm}	time taken to travel between supplier and manufacturer
t_{mr}	time taken to travel between manufacturer and retailer
L_s^s	liability cost per unit with contamination at supplier and recall at supplier
L_m^s	liability cost per unit with contamination at supplier and recall at manufacturer
L_r^s	liability cost per unit with contamination at supplier and recall at retailer
L_m^m	liability cost per unit with contamination at manufacturer and recall at manufacturer
L_r^m	liability cost per unit with contamination at manufacturer and recall at retailer

contamination. Thus, the devastating financial consequences of outbreaks do not necessarily target the actual source of the contamination. For instance, in the US in 1997, Hudson Foods, a supplier of burgers to Burger King, recalled 25 million pounds of hamburger meat due to *E. coli* contamination. The company was not able to determine the origin of the outbreak (suspected to be one of its suppliers) and eventually went out of business [9]. Following the 1995 *E. coli* outbreak, the Jack-in-the-Box fast food outlet saw its sales drop by 25% and was the subject of a number of expensive lawsuits from families of the children who died or became ill [21]. Therefore, there is a clear incentive for firms to move towards closer strategic partnering relationship with suppliers to establish transparent information communication as well as legal liability costs to account for potential safety problems.

Several recent developments at national and international levels aim to facilitate traceability of food products. For instance, under the EU food traceability law published in 2007 [5], it must be possible to track any food, feed, food-producing animal or substance that will be used for consumption through all stages of production, processing and distribution. Accordingly, all food and feed operators must be able to identify where their products came from and where they are going and be able to quickly provide this information to the authorities. However, the specific level of traceability and the employed technology is different in different cases. A majority, if not all, of perishable food items that pass through these supply chains are identified by their class-level information (i.e., a lb of spinach). Invariably, bar code is the identifier of choice for these items.

In a supply network setting, the choice of a certain level of traceability (e.g. class-level vs. item-level) as well as the traceability technology (e.g. bar code vs. RFID) has not only considerable cost implications but also strictly influences the liability of different members in the supply network. We define liability as the cost that is incurred when contamination is detected. We do not consider the consequences of food-borne illness when contamination remains undetected as well as related legal and health implications of contamination. Ultimately, identifying the contamination source facilitates (a) the ease of isolating and rectifying the cause of contamination, (b) payment for caused damage by the 'culprit', and (c) exonerating and/or compensating the 'innocent' parties.

In general, when uniquely identified, the offending party (i.e., node at which contamination occurs) pays the product recall cost. Naturally, each supply network member prefers a combination of a cheaper high-level of traceability and a less precise technology to shift the liability toward other members. Therefore the product price between, for example, a supplier and a manufacturer is negotiated according to their agreed liability. Thus, each operator must select the level of traceability and the traceability technology based on its own cost-benefit analysis.

We analyze the effect of selecting a traceability level and technology for each supply network operator in a perishable food supply network. Specifically, as in Dai et al. [3], we consider identification of items at SKU-, batch-, and item-levels. We do not concern ourselves with the specificities of these terms – i.e., item-, batch-, and SKU-levels-other than to state that item-level represents the finest level of granularity generally considered in the context of interest (i.e., a jar of peanut butter, a bag of peanuts), SKU-level deals with the other extreme. Please note that 'batch-level' does not necessarily represent entities in terms of *production batch* but rather a level of granularity that is in-between 'item-' and 'SKU-' levels. We claim that despite the commonly used higher levels of visibility information, item-level or even case-level traceability information generated using RFID technology might be more appropriate in facilitating identification of items at a lower level of granularity (e.g. [23]).

The remainder of this paper is organized as follows: An overview of existing related literature is provided in the next section. Preliminaries related to this study are discussed in Section 3. The case where the contamination is known to have occurred at the supplier level is discussed in Section 4. This is followed by the case where contamination is known to have occurred at the manufacturer-level in Section 5. In Section 6, we consider the scenario where contamination occurs at the manufacturer level and the contamination source node is exactly identified. We conclude the paper in Section 7 with a brief discussion on the findings in this paper and related policy implications.

2. Related literature

A general discussion on product safety and security in global supply chains is provided by Marucheck et al. [13]. In addition to providing an overview of existing literature on product safety, they