Omega 53 (2015) 41–48

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Decision support for risks managers in the case of deliberate food contamination: The dairy industry as an example ☆

Beate Pinior [a,b,c,*], Franz J. Conraths [a], Brigitte Petersen [b], Thomas Selhorst [d]

[a] Friedrich-Loeffler-Institut, Federal Research Institute for Animal Health, Institute of Epidemiology, Südufer 10, 17493 Greifswald - Insel Riems, Germany
[b] Institute of Animal Science, Preventive Health Management Group, University of Bonn, Katzenburgweg 7-9, 53115 Bonn, Germany
[c] University of Veterinary Medicine Vienna, Institute for Veterinary Public Health, Veterinärplatz 1, 1210 Vienna, Austria
[d] Federal Institute for Risk Assessment, Unit Epidemiology, Statistics and Mathematical Modelling, Max-Dohrn-Straße 8-10, 10589 Berlin, Germany

ARTICLE INFO

Article history:
Received 7 December 2013
Accepted 19 September 2014
Available online 5 December 2014

Keywords:
Greedy algorithm
Terrorist attacks
Contingency plan
Dairy industry

ABSTRACT

Dairy farms were identified, which can be included in a contingency plan set up to prevent or mitigate the consequences of deliberate contamination of a food supply chain. The deliberate introduction of a contamination into the supply chain of milk was simulated in a scenario where milk producers serve as the entry sources and consumers of milk represent the target to be affected by the contamination. It is shown that the entry sources have an impact on the damage caused, i.e. in terms of the number of consumers reached. A contingency plan is provided that contains a list of entry sources ranked according to their impact on the damage to consumers. To generate this list, a computer program was developed that simulates the impact of the contaminations on consumers via the trade of contaminated milk. Possible variations in the trade links between milk producers, dairies and consumers as well as between dairies are considered. It is investigated how these trade links alter the generated list of entry sources.

The results indicate that, regardless of the actual milk trade flow, control measures should be introduced on 39% of the milk producers in order to minimize the damage. The identification of suitable entry sources may help risk managers to focus on these farms in a contingency plan that improves the sensitivity of control activities related to deliberate contamination.

1. Introduction

Risks in supply chains can come from a large number of sources [1–9] and thus their prevention leads to a broader view of risk management [10]. For example in the study of Wu and Olson [11], financed risks of enterprises were addressed and models were applied in order to support their investment decision-making [11]. Other studies estimated the risks of a food contamination in order to provide the risk-informed decision-making on food safety management issues [12,13]. However, Enterprise Risk and Enterprise Risk Management (ERM) have attracted a great deal of attention, especially in recent years [14]. But there are slightly different views on ERM [14,15]. In general, ERM is defined as a systematic and integrating approach to managing all risk factors which an organization is faced with [15] and thus represents the most effective way for companies to manage or mitigate their risks [10]. Besides [15], COSO [16] defines ERM as "a process [that is] effected by an entity's board of directors, management and other personnel, applied in strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity objectives". Similarly, Olson and Wu [17] define ERM as "the integrated process of identification, analysis and either acceptance or mitigation of uncertainty in investment decision making". Against this theoretical background, our research framework rests on the definition of risk management provided by [17] with a focus on the decision-making of supplier selection under consideration of their vulnerability to terrorist entry sources. The food supply chains are tempting targets for terrorists as attacks on these systems may destabilize the economy and disrupt the flow of foods [18]. Defense preparedness in this field is often in the hand of the private sector [19]. For example, companies in the food sector apply for certifications of their food defense management strategies [20]. Rasco and Bledsoe [19] claimed that about 80% of consumers consider the food supply as vulnerable to attacks. Several incidents of intentional contamination in the food supply chain underline its vulnerability [21–25]. For instance, at least 751 people were affected due to deliberate

☆Processed by Ben Lev.

* Corresponding author at: University of Veterinary Medicine Vienna, Institute for Veterinary Public Health, Veterinärplatz 1, 1210 Vienna, Austria. Tel.: +43 1 250773531; fax: +43 1 250773590.
E-mail address: Beate.Pinior@vetmeduni.ac.at (B. Pinior).

http://dx.doi.org/10.1016/j.omega.2014.09.011
0305-0483/

contamination of salad bars in Oregon, USA, in 1984 by members of a religious commune [25–27]. Another case occurred in 2003, where approximately 100 people were affected after consumption of ground beef that had been contaminated by a supermarket employee [25,28]. According to Sobel et al. [29], an intentional contamination of the food supply may be similar to an accidental contamination. In this context, the likely size of damage caused by an attack can be inferred from observed unintentional foodborne disease outbreaks [29]. In 1994, for example, a large outbreak of *Salmonella enteritidis* in the United States affected approximately 224,000 people after accidental contamination of pasteurized liquid ice cream [22,29,30].

However, the above mentioned studies are based on the assumption that the selection of the entry sources for a deliberate contamination of the supply chain can be random, because the consequences of deliberate of accidental contaminations cannot be distinguished from each other.

In this paper, we concentrate on the hypothetical threat posed by a deliberate introduction of a pathogen or toxins into the milk supply chain. We focus on a scenario, where the milk producer (dairy farm) is used as the entry source for a contamination and where milk consumers are the target of the attack [13]. We assume that a potential attacker would aim at reaching a maximum spread of the contaminated milk and at using a minimum number of milk producers as entry sources for the contamination. Ideally, the attacker would aim at reaching the maximal spread of contaminated milk by contaminating the first milk producer in the network of milk trade. If the attacker was not stopped after the first assault, he would contaminate another milk producer as a second entry source if this contamination cause larger increase of infected consumers compared to the first entry sources. The attacker has achieved his goal, when all consumers have been supplied with the contaminated milk. Due to the fact that the milk trade between milk producers, dairies and consumers as well as between dairies in the milk supply chain is dynamic [31,32], we hypothesize that trade links may influence the selection of milk producers that are used as the entry sources for the contamination by the attacker.

However, the most important task during a foodborne outbreak is to identify the source of the food contamination and its entry sources [33]. Thus, the aim of this paper is to provide the following information for risk managers on the chosen scenario: Firstly, which entry sources would be chosen by a hypothetical attacker, if data on the commodity flows became publicly available? Secondly, how many entry sources would the attacker have to choose to reach all consumers with contaminated milk in Germany? Thirdly, in which sequence would an attacker choose potential entry sources? Fourthly, are there milk producers who can be selected independent of the flow of milk to induce maximum damage? Fifthly, in the context of ERM, what strategies can be derived to prevent or mitigate the consequences of deliberate contamination with scant resources? These questions were answered by proposing a contingency plan.

To prevent that the results of this research are used as an instruction for a potential attacker, we work with highly aggregated and anonymous data. Moreover, we use a random gravity model to generate the trade connections between the actors in the milk supply chain. Furthermore, we focus on the spread of hypothetically contaminated milk via trade. Our investigation does take any features into account that are specific for particular milk producers, such as bio-security measures. Nevertheless, we expect that contamination of milk in dairy plants is less likely than in farms due to restricted access to the dairy plants. Relevant characteristics of milk, the kind of biological agents or toxins, individual dispositions like the age of people [34–37] and internal processes like pasteurization [38–43], which may influence the vulnerability of the consumers to contamination, but also the spread of contamination [32], are not considered in this paper.

2. Material and methods

2.1. The generation of the milk trade network

The underlying milk trade network has been described in detail elsewhere [32]. In brief, the term "milk trade network" comprises the trade connections between milk producers (P) and dairies (D), dairies and consumers (C) and the trade connections between dairies. On the one hand, the horizontal flow of milk between dairies (inter-dairy trade) and on the other hand, the vertical flow (without inter-dairy trade) between milk producers, dairies and consumers is taken into account. All milk producers of a country and all consumers of a municipality were aggregated into one milk producer node or one consumer node, respectively. The milk trade network consists of 12,597 nodes, with $P=294$, $D=80$ and $C=12{,}223$.

Data on the trade relations from milk producer nodes to dairy nodes are available in accordance with the German law of market regulations for goods (Marktordnungsmeldeverordnung). Information on the trade connections between dairy nodes and consumer nodes as well as between dairy nodes was not available and these trade connections were predicted through a standard randomized gravity model [32]. The standard randomized gravity model [44–47] was based on the assumption that the probability of two market actors trading with each other is proportional to the supply and demand of the respective actors and indirectly proportional to their distance to each other [32,46,48]. Further information on the generation of the German milk trade network can be found in [32]. However, different trade networks are required due to the random nature of the model [32]. One hundred different trade networks were therefore created, consisting of 50 trade networks with inter-dairy trade and 50 without inter-dairy trade.

2.2. Greedy algorithm and objective functions

To identify the number and the rank-order of milk producer nodes, which may cause maximum damage in terms of the number of contaminated consumer nodes, the greedy algorithm was used. This algorithm can solve optimization problems [49–51] and is applied under the predetermined objective function to find the most appropriate milk producer nodes (P) as entry sources for a contamination to cause maximum damage on the condition that maximum spread of contaminated milk in association with a maximum number of contaminated consumer nodes (C), so that the number of milk producer nodes involved in spreading the contamination is minimal (Eq. (1)).

$$\max |\{c : c \in C;\ \min| \ \{p : p \in P\}|, p \in D, c \in D, D \in R\}| \quad (1)$$

In this context, there is a second condition requiring that trade connections between milk producer nodes and dairy nodes ($p \in D$) as well as between dairy nodes and consumer nodes ($c \in D$) exist. Furthermore, the condition should be reflexive and transitive (R), as trade connections between dairy nodes should be considered in our model. However, the objective function considers only the trade volume (ν) and the trade connections of the milk producer nodes, their associated dairy nodes and the consumer nodes.

294 candidate of entry sources were hypothetically contaminated in the computer simulations, selected and sorted according to the extent of the resulting damage caused dependent on the respective milk trade flow.

The greedy algorithm starts with the identification of the candidate set of solutions. A candidate is selected for the solution when it maximizes the selection function. Let S represent the