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APPLICATION OF MODELS FOR SAFEGUARDING THE MILK SUPPLY CHAIN

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“Essentially, all models are wrong,
but some are useful.”

George Edward Pelham Box and Norman R. Draper (1987)

Empirical Model-Building and Response Surfaces, p. 424

(Statistician)

ABSTRACT

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KURZBESCHREIBUNG

Ziel der vorliegenden Arbeit war es, ein Simulationsmodell zu entwickeln, um ausbreitungsfördernde Akteure und Warenströme für den Fall einer hypothetischen Kontamination in der Milchwirtschaft zu identifizieren. Basierend auf den Modellergebnissen wurden Strategien zur Sicherung der Milchversorgungskette für Entscheidungsträger abgeleitet.

Der erste Schritt für die Erstellung eines Simulationsmodells war die Entwicklung eines konzeptionellen Modells, in dem die Akteure und die handelsstrukturellen Verknüpfungen zwischen den Akteuren beschrieben werden. Bei der Quantifizierung dieser Handelsbeziehungen konnte auf umfangreiche Datensätze über die realen Warenströme in der Milchwirtschaft zurückgegriffen werden. Aufbauend auf dem konzeptionellen Modell wurde im zweiten Schritt ein Modell aus der Wirtschaftswissenschaft zur Vorhersage von Handelsbeziehungen mit Optimierungsalgorithmen neu kombiniert, um einerseits die räumliche Ausbreitung einer hypothetischen Kontamination, unter Berücksichtigung divergierender Warenströme zwischen den Akteuren, zu simulieren. Die simulierte Schadenslage wurde durch die charakteristischen Modellgrößen Virulenz, Vulnerabilität und Resistenz der Akteure sowie die geografische Reichweite einer Kontamination quantifiziert. Insbesondere galt es, den Einfluss des Handels zwischen den Molkereien auf die räumliche Ausbreitung einer Kontamination abzuschätzen. Die Grundlage für die durchgeführte Modellierung bildeten 500 Handelsnetzwerke, die 61,43% der existierenden Warenflüsse von Konsummilch in Deutschland abbilden. Diese Netzwerke umfassen variierende Handelsbeziehungen zwischen 294 Milcherzeugern, 80 Molkereien und 12223 Konsumenten. Anderseits wurde ein Managementplan für Entscheidungsträger konzipiert, aus welchem Überwachungsmaßnahmen zur Minimierung der Schadenslage abgeleitet wurden. Die Modellergebnisse zeigen Akteure und Strukturen auf, die fördernd für die Ausbreitung einer hypothetischen Kontamination in der Milchwirtschaft sind. Zum einen kann bei stattfindendem Handel zwischen den Molkereien das Risiko für den Verbraucher im Mittel bis zu dreimal höher sein mit der hypothetisch kontaminierten Milch beliefert zu werden bzw. die Ausbreitung durch den Milcherzeuger kann im Mittel bis zu viermal höher sein, als ohne diesen Handel. Zum anderen zeigt der erstellte Managementplan, dass unter dem vorgegebenen Szenario, Kontrollmaßnahmen für 40% der Milcherzeuger eingeleitet werden müssten, um die Schadenslage zu minimieren.

ABSTRACT

The objective of this thesis was to develop a simulation model in order to identify actors and flows of goods, which can promote the spread of a hypothetical contamination in the dairy industry. Based on the model results, strategies to safeguard the milk supply chain were derived for decision-makers.

The first step for creating a simulation model was to develop a conceptual model, in which the actors and the structural trade links between the actors are described. For quantifying these trade links a substantial amount of data about the real flow of goods in the dairy industry could be used. Based on the conceptual model, an economic model for predicting trade relations was newly combined with optimization algorithms. On the one hand, for simulating the spatial distribution of a hypothetical contamination, taking into account various flows of goods between the actors. The simulated damage situation was quantified in terms of the distinctive model parameters virulence, resistance and vulnerability of actors as well as the geographical range of a contamination. In particular, it was necessary to assess the impact of trade between the dairies on the spatial spread of a contamination. The basis for the carried out modeling formed 500 trade networks that represent 61.43% of the existing flows of goods of processed milk in Germany. These networks comprise varying trade relations between 294 milk producers, 80 dairies and 12,223 consumers. On the other hand, a management plan for decision-makers was designed, where surveillance measures for minimizing the size of damage were derived from.

The model results indicate that actors and structures exist that promote the spread of a hypothetical contamination in the dairy industry. First, the risk for the consumer to be supplied with hypothetical contaminated milk is up to three times higher on average, if a trade between dairies exists, compared to the neglect of the trade. In this context, also the spread of contaminated milk through the milk producers can be up to four times higher on average. Second, under consideration of the predetermined scenario, the management plan shows that control measures should be introduced on 40% of the milk producers in order to minimize the damage.

CONTENTS

GENERAL INTRODUCTION

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1. GENERAL INTRODUCTION

Chapter 1 gives an overview about the modeling process. For this purpose, the definition of models, the strengths and weaknesses of models, the use of the model results for decision support as well as the different classifications of models will be thematized. Furthermore, the steps for model development and the objectives of this thesis are outlined.

DECISION SUPPORT AND MODEL DEVELOPMENT

In crisis time a minimum number of intervention measures and thus efficient allocation of resources can be introduced by decision-makers and crisis-managers if data about the damage situation are available and prepared. The main reason for this is that processed data provide information (Harsh et al., 1981) from which knowledge can be generated and this knowledge can be used to initiate actions (Möws, 2008). To sum up, the decision-making processes depends on the availability of information (Breuer et al., 2008). In this context, four different categories of information are required for decision support (Harsh et al., 1981): descriptive, comparative or diagnostic, predictive and prescriptive information (Harsh et al., 1981; Petersen, 1986; Breuer et al., 2008; Breuer, 2011). According to Wilke and Petersen (2012) descriptive information are e.g. situation report; comparative information represent e.g. commodity flow analyses; predictive information includes the posing of the question "what-if" (Harsh et al., 1981), which can be answered by simulations (Breuer, 2011). The question "what should be done" (Harsh et al., 1981) is answered by the utilization of prescriptive information (Breuer, 2011), which includes e.g. crisis manuals (Wilke and Petersen, 2012). However, the decision-making can also be supported by the development of a model (Balci, 1994; Zessin, 2004; Keeling, 2005; Rubel, 2005). For instance, the simulation of certain scenarios (simulation model) can lead to new insights for decision-makers, especially if certain scenarios are too costly or not possible to carry out in practice (Maria, 1997), e.g. the estimation of the spatial spread of a contamination. Furthermore, models have the advantage of providing a framework condition that allows us to communicate and to conceptualize our perceptions about the system (Keeling, 2005). This is especially realized by mathematical models, because they have one of the most rigorous languages in order to define accurately our ideas about the system (Keeling, 2005). In this context, a system consists of a number of elements and structural links between the elements that operate with each other (Seila, 1995; Zessin, 2004), so that a purpose of the system can be assigned (Forrester, 1972; Bossel, 1987).

It should be noted that persons, e.g. decision-makers, who use the results of model, should understand the weaknesses and strengths of a model because „models are neither infallible nor a panacea" (Keeling, 2005). We will begin with the limitations of models.

First, as described by Krcmar (2005) models are subjective-, purpose- and perspective-relative. A model is thereby an abstraction (Balci, 1994; Seila, 1995; Zessin, 2004; Rubel, 2005; Petzoldt, 2011) and a simplification of a system respectively (Seila, 1995; Maria, 1997; Keeling, 2005). Consequently, a limitation of the models is caused by the fact that models represent only an approximation of the considered system (Keeling, 2005). The main reason is that the elements of a system can only be studied with reasonable effort, when a simplification of the system takes place by an aggregation of the system elements (Bossel, 1987) or by determination of system limits or by a decomposition of the system into subsystems (Balci, 1994; Hofmann, 2003). As described by Hofmann (2003) the decomposition of the system may be carried out in different ways, e.g. according to the elements, databases, and functions or on cause-relationships, etc. (Hofmann, 2003).

Second, the limitations of models are caused by the availability of data (Keeling, 2005). The modeling depends largely on data quality and data quantity and is described by Zessin (2004) and Rubel (2005) as key elements of modeling. If there is no or only inadequate data or poor data quality available the model results often might be also of the same quality.

Finally, models are developed in order to solve a certain task (pragmatics) or a special problem (Balci, 1994). Therefore models are only intended for this purpose, which limits the scope of application of the model (Bossel, 1987). In conclusion, this means that different models can be developed for one system (Hofmann, 2003; Petzoldt, 2011) and with a single model different model results can be calculated (see example by Keeling, 2005). This can also be seen as weakness.

The strength of the model results from the fact that models can provide new insights and new information for decision-makers. In this context, three kinds of strengths of models are distinguished by Keeling (2005): On the one hand, models provide information, which can be used to make a forecast e.g. of the extent and location of damage situation, so that adequate interventions can be introduced. On the other hand, models can be used to extrapolate from known values to probable values (Keeling, 2005). The power of models can be derived from the fact that they can integrate the knowledge about one system and translate it into larger spatial scale (Keeling, 2005). Other strengths of models are that a large number of parameters can be integrated, exchanged or extended in the model and their effects on the behavior of the system can be analyzed. Furthermore, models can be used e.g. to test strategies (Selhorst et al., 2001) and to simulate outbreak scenarios (Pinior et al., 2012a) without any present damage situation (Keeling, 2005). As a result, information for decision support could be provided in order to introduce measures in peacetime as well as in crisis time. In Summary, the model development (Bossel, 1987) and the model results can lead to new insights on the behavior of the system (Barton and Meckesheimer, 2006), which otherwise had remained undetected (Bossel, 1987).

General, the term “model” is very broad (Petzoldt, 2011). In the literature epidemiological models (Tischendorf et al., 1998; Ducheyne et al., 2011; Staubach et al., 2011), mental models (Sterman, 1991), communication and information models (Kasper et al., 2008; Pinior, 2010; Slütter et al., 2010; Pinior et al., 2012b), verbal models (Keeling, 2005), laboratory models (Petzoldt, 2011), economic models (Baier and Bergstrand, 2009), microbiological models in combination of shelf life predictions (Bruckner et al., 2013) and mathematical models etc. (Petzoldt, 2011) were distinguished. The main reasons for the wide range of models are that different systems can be modeled, different model purposes exist and an interdisciplinary overlap of topics can be found in models as well as different classification options for models can be taken into account (Hofmann, 2003).

Using the example of mathematical models, Figure 1 shows that mathematical models can be classified according to the a) state of the model (Sterman, 1991; Maria, 1997; Zessin, 2004; Rubel, 2005; Petzoldt, 2011), b) purpose of the model (Sterman, 1991; Zessin, 2004), c) modeling techniques d) degree of abstraction (Hofmann, 2003) or e) to the data quality, data quantity and the state of knowledge (Zessin, 2004; Rubel, 2005).

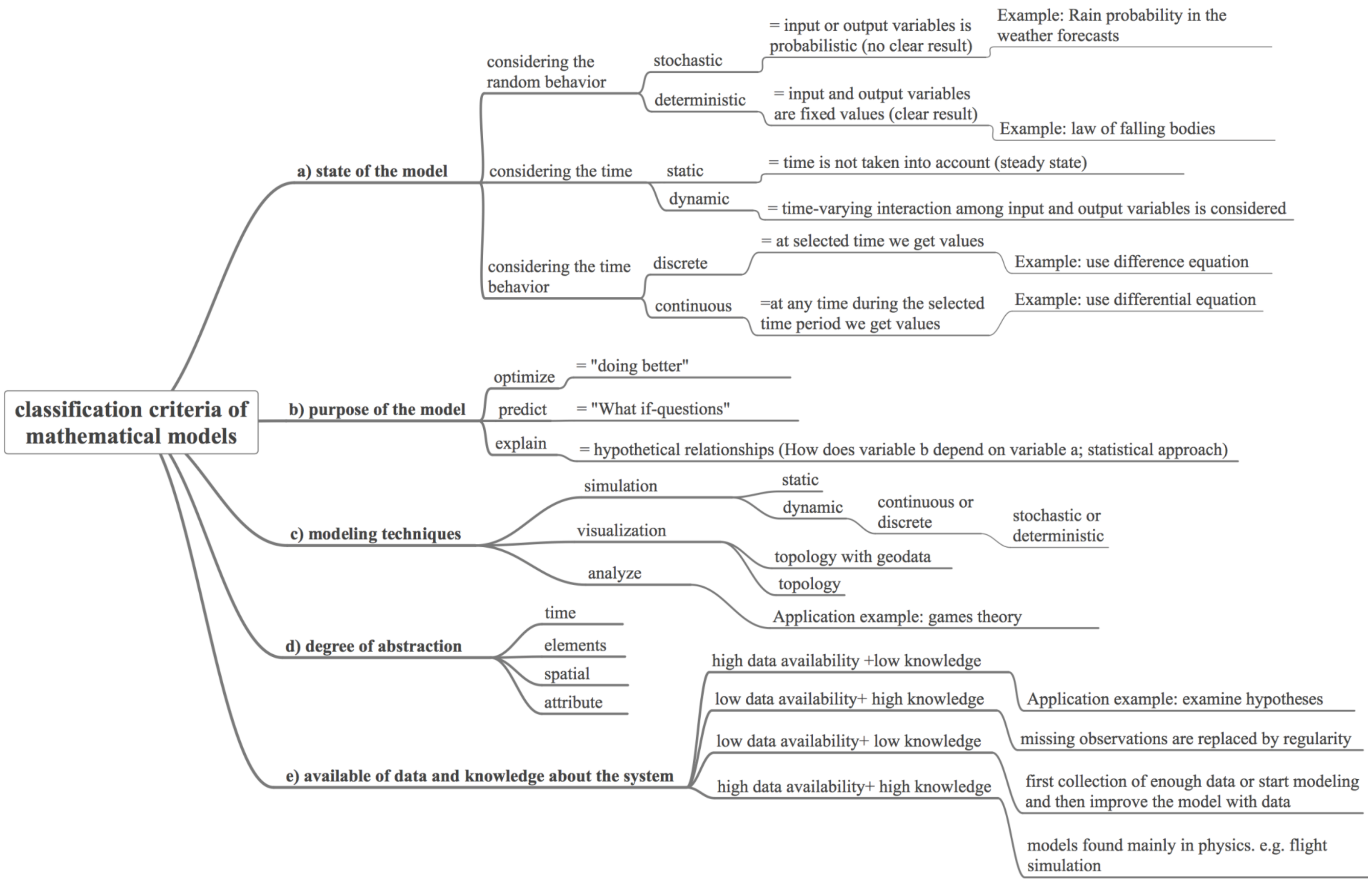

Figure 1. Overview about the classification ways of mathematical models

(Source: author’s own illustration; based on the findings of the mentioned authors in the continuous text)

In principle, it is also possible that an overlap within and between classification criteria of models is given (Figure 1). An example for inter- and intra-overlapping of classification is given by the fact that most simulation models are stochastic (Seila, 1995) and dynamic (Maria, 1997). Stochastic models are statistical models and the generated results are based on probability statements (Rubel, 2005). In this context, the values of variables cannot be predicted with certainty, because of their random nature (Seila, 1995; Zessin, 2004). However, figure 1 gives only an overview about the classification criteria e.g. Balci (1998) has described that simulation models could be further divided into self-driven (probabilistic) and trace-driven (retrospective).

Figure 2 gives an overview of the approach in order to develop a simulation model. The first step in the modeling is the detailed description of the given system, by consideration of its contained elements, its functions and its structural links between the elements (Bossel, 1987) as well as an quantification of their relationship (Bossel, 1987). The main reason for this modeling step is that the conceptualization of a model requires knowledge about operating rules of the system (Pritsker, 1998) so that relevant elements and structural links can be recognized (Bossel, 1987). In the literature, the description of the system is also described as a conceptual model (Balci, 1998; Foss et al., 1998; Hofmann, 2003; Becker and Pfeiffer, 2006). In general, a conceptual model is not sufficient to determine the behavior of a system (Bossel, 1987) at certain conditions. Therefore, it is necessary to transfer the relevant information from the conceptual model into a formal (mathematical or logical) model (Bossel, 1987). Relevant information are defined by the particular research problem. A model represents the most important elements of the system as well as the structural links between them (Seila, 1995). Afterwards, the formal model is transferred into a computer program (Bossel, 1987) and simulated (calculated) or optimized (Figure 2). The results of a simulation have a predictive character. After Harsh and coauthors (1981), the provision of predictive information is only adequate, when an evaluation was carried out. Two kinds of evaluation can be distinguished in the modeling process, verification and validation.

The verification of the model considers the accuracy of transforming a problem formulation into a model requirement specification (Balci, 1997, 1998). The model verification substantiates that the model is built right (Balci, 1997, 1998; Robinson, 1997). Or in other words, does the model fulfill its function (Zessin, 2004).

According to Seila (1995) the proximity to reality of the model should be determined on the real system before it can be used for decision making. In the literature, this is also referred as model validation or in other words „building the right model" (Balci, 1997; Robinson, 1997; Balci, 1998). According to the studies by Seila (1995), Foss et al., (1998) and Zessin (2004) a validation should be carried out, in which the model results are compared with the data from the real system in order to ensure that both do not differentiate substantially (Seila, 1995). This has been carried out only in a few studies (Selhorst, 2000; Martínez-López et al., 2012), because data are not always available (Stärk, 1998). In principle, a complete conformity between the system and the developed model is not possible (Schmidt, 1985).

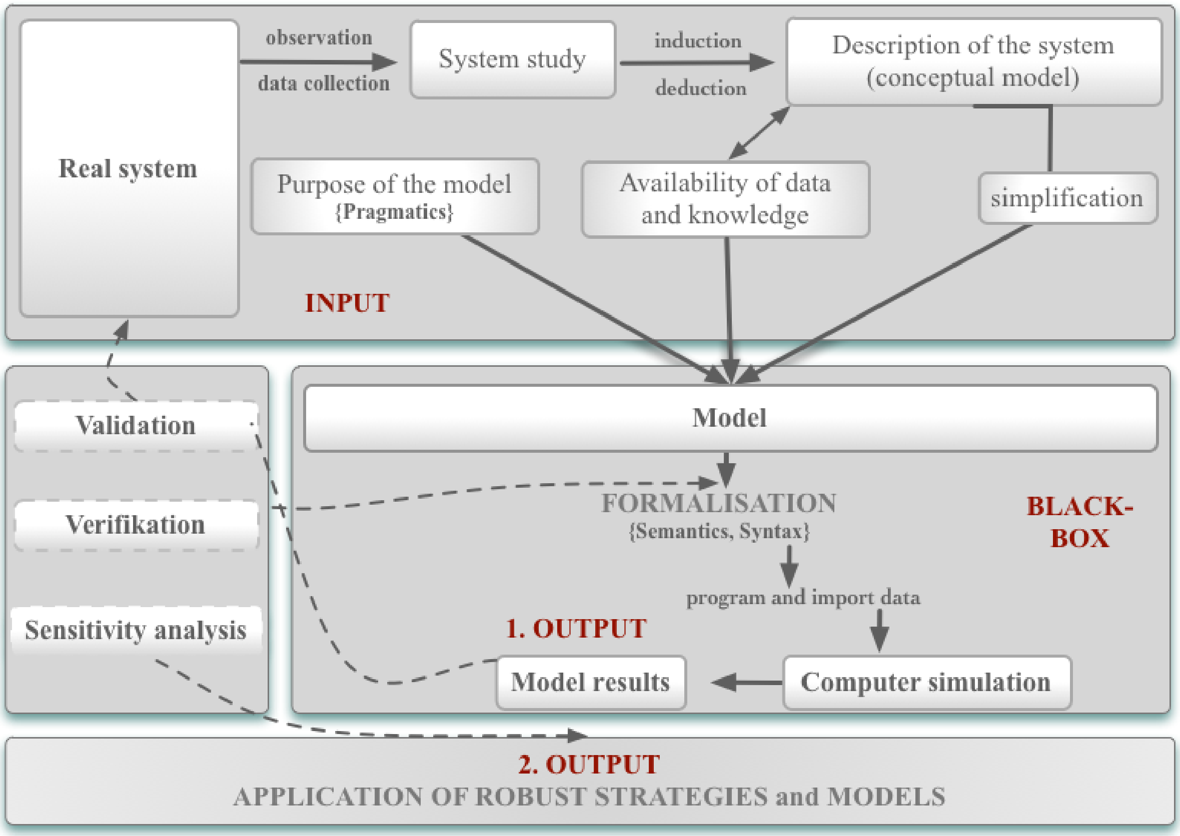

Figure 2. Overview about the steps for model development (Source: author's own representation modified according to Bossel, 1987; and partially based on the findings of the studies by Balci, 1994, 1997, 1998; Hofmann, 2003 and by Zessin, 2004).

During the model testing, detected deviations can be integrated into the modeling so that a continuous improvement of model formulation and model parameters can be achieved (Bossel, 1987). Moreover, there are many different methods for performing validation and verification (Banks, 1998). A good review on existing validation techniques can be found in the manuscripts of Balci (1997 and 1998), where about 75 different verification, validation and testing techniques are shown.

In order to derive robust strategies from the model and to develop robust models for decision support, a sensitivity analysis should be carried out. In the context of a sensitivity analysis the parameters of the model (input variables) can be changed and their effects on the model results (output variables) and model behavior are analyzed (Zessin, 2004). According to Balci (1994), by using the sensitivity analysis the values of the input parameters and variables can be identified to which the behavior of the model is very sensitive. In the studies by Kleijnen, (1995); Chan et al., (1997) and by Melas, (1997) other reasons for conducting a sensitivity analysis are given. In the case of an absent or very slight variation within tolerable limits the model is regarded as robust (Zessin, 2004).

Models are used in many research disciplines. For decades, models have been a part of agricultural and food science. For example, Petersen (1986) has developed a model in order to generated predictive and prescriptive information with regard to the diagnostic test results and the occurring of diseases in pigs, so that decisions for the operational management can be derived. This thesis is based on the basic idea of the work by Petersen (1986). The main differences between the present study and Petersen (1986) are: Firstly, in this work the system "milk supply chain" and the respective purpose of the system, „the supply of the consumers with milk" is considered. Secondly, our model is a computer simulation model with predictive, stochastic and static attributes. Thirdly, in addition to the predictive and prescriptive information, descriptive and comparative information for the considered milk supply system will also be provided. In this way a connection between the four categories of information, which are necessary for decision support and the development of models for the gaining of new insights about the system behavior for decision-makers, are generated.

In this context, the aim of this thesis is to develop a simulation model in order to identify actors and flows of milk, which can promote the spread of hypothetical contamination due to the trade connections in the dairy industry, by taking into account various horizontal and vertical flows of milk. Based on the model results, management strategies to safeguard the milk supply chain will be derived for decision-makers.

First, to achieve this goal it is necessary to get an overview about the flow of goods and the actors in the milk supply chain (system) in order to obtain an insight into the operation of the system. This step can be associated with the collection of descriptive information. This step is followed by the application of a network analysis on the milk supply system (comparative information) in order to analyze the commodity flows in the dairy industry. The actors in the milk supply chain, which can promote the spread of hypothetical contaminated milk, are defined and quantified with respect to the virulence, vulnerability and resistance (see section iii) by application of a simulation model (predictive information). Moreover, “risk” actors should be identified, which are suitable to be included in a control management plan (also called contingency plan) set up to prevent or mitigate the consequences of damage situation. This step is connected with the provision of prescriptive information.

More specifically, the following research questions and issues are addressed in chapter 2 (Figure 3):

i. **Description of the milk supply chain (Conceptual model)**

- **Descriptive information:** Which actors, functions and structural linkages between the actors in the milk supply chain (system) are existing in order to supply the consumers (purpose of the system) with processed milk?;

ii. **Analysis of the milk supply chain by using the network analysis**

- **Comparative information:** Analysis of the vertical and horizontal trade structures with regard to the trade volume, number of trade partners, the geographical distances and the density of trade connections between trade partners in order to extend the knowledge about the milk supply system.

iii. **Application of a gravity model in order to set up the simulation model**

- How is it possible despite the lack of data to generate missing structural links between the actors for the model development?;
- **Predictive information:** Which impact have the vertical and horizontal flows of milk on the spread of a hypothetical contagion?;
- **Predictive information:** How do the virulence, resistance and vulnerability of actors as well as the geographical range of a contamination differ with regard to various flows of milk?;

iv. **Development of a contingency plan for decision-makers by the use of optimization algorithms**

- **Prescriptive information:** How can relevant actors be selected by decision-makers with scant resources, so that the damage situation could be avoided or minimized regardless of the flows of milk?
- **Prescriptive information:** In which sequence should the relevant actors be controlled?

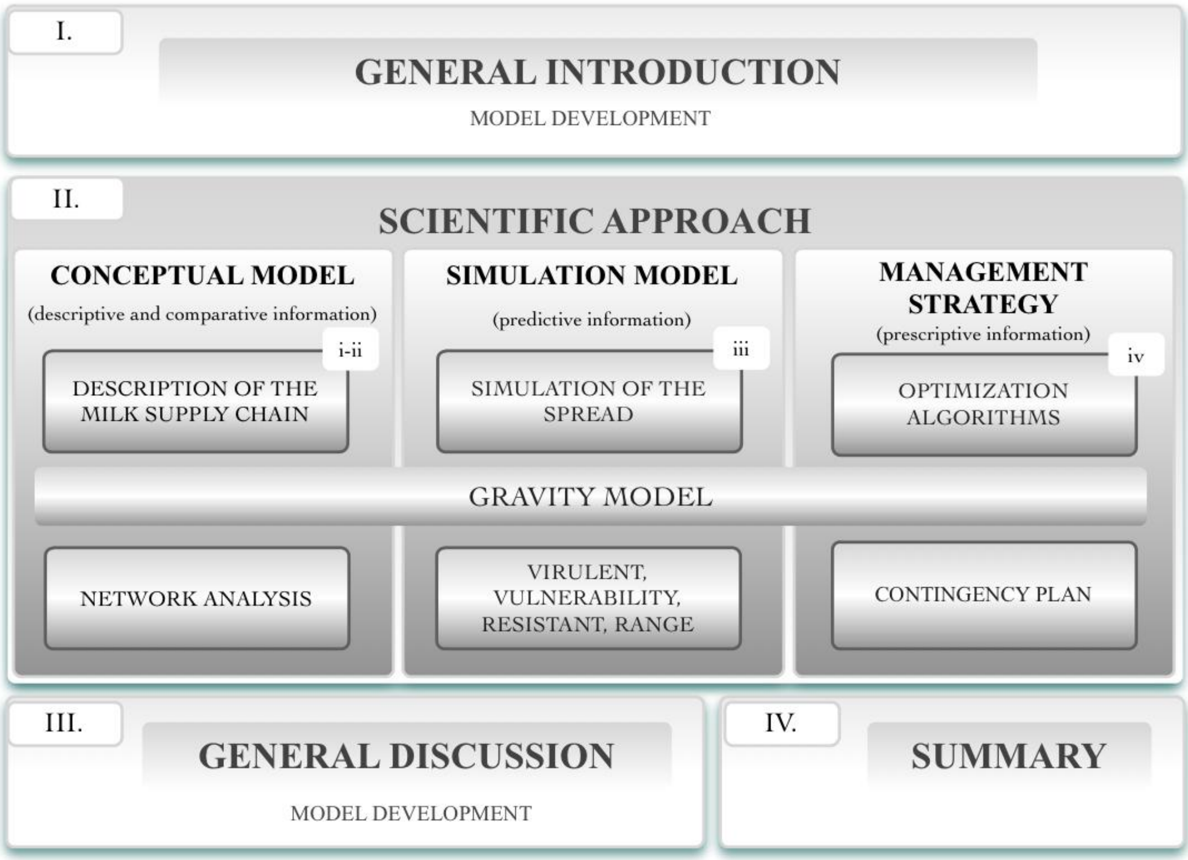

Figure 3. Outline of the thesis (Source: author's own illustration)

Chapter 2 is based on three research manuscripts and is divided into four sections. The sections (i) to (ii) include parts of the contents of the manuscripts 5.1. The sections (iii) and (iv) are based on the Paper 5.2 and 5.3 respectively. The used source of code is provided in section 5.4. In addition, a conclusion and an outlook for further research questions will be given. In Chapter 3, some critical aspects related to the model development and the availability of data specific for the dairy industry are discussed. The thesis is concluded by a summary.

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SCIENTIFIC APPROACH

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2. SCIENTIFIC APPROACH

Chapter 2 represents the scientific approach to develop a simulation model and to derivate management strategies in order to safeguard the milk supply chain.

At the beginning of this chapter 2, an introduction to the problem definitions and objectives of this thesis are given. It is followed by the problem-solving approaches. Generally, this chapter comprises four sections and is hereinafter listed with (i-iv) according to the questions and issues previously mentioned in the chapter 1.

2.1 INTRODUCTION[1]

In the case of an outbreak of a foodborne disease, delays in the identification of the source of the food contamination can harm the health of consumers, cause economic losses and incur social and political damages for the country (Ercsey-Ravasz et al., 2012). This can be underpinned by the consequences of the three weeks delay in identifying the origin of the sources of *enterohemorrhagic Escherichia coli* (E.coli.) contamination in Germany (Ercsey-Ravasz et al., 2012). The complexity of national and international trade structures obscures a clear view of trade flows and, consequently, it is often impossible to unravel complex trade links quickly (Pinior et al., 2012a). The trade of agricultural goods, including about 70% of food products, has almost doubled since 2000 (Fricke, 2010) and could be used as an example of the complexity of the trade structures. It is generally accepted that trade structures can be relevant for the spread or distribution of pathogens, toxins or of animal diseases and was addressed in numerous studies (Hennessy et al., 1996; Käferstein et al., 1997; Fritzemeier et al., 2000; Ortiz-Pelaez et al., 2006; European Commission, 2008; Dubé et al., 2009; Martínez-López et al., 2009; Natale et al., 2009; Lentz et al., 2011; Natale et al., 2011). The important role of trade in the spread or distribution of a contamination in the agricultural and food sector becomes apparent through a multitude of outbreak cases.

The largest known foodborne outbreak in Germany occurred in 2012, caused by imported frozen strawberries or products made from them presumably contaminated with *norovirus* (RKI, 2012). In this case, 10,950 people were diseased in Germany (RKI, 2012). The frozen strawberries were distributed from China in eight different countries (Canada, Denmark, Germany, Iceland, Netherlands, Poland, Russian Federation, United Kingdom; RASFF Portal,

[1] In the introduction there are some sections, which were taken verbatim from the publications Pinior et al. 2012a,b,c

2012a). An outbreak of hemolytic uremic syndrome (HUS) and diarrhea related to infections with *Shiga toxin–producing Escherichia coli* (STEC) caused by contaminated fenugreek seeds for sprouting from Egypt happened in 2011. It was centered in northern Germany (Buchholz et al., 2011; Wilking et al., 2012), but cases have been also reported in all German federal states (Askar et al., 2011; Frank et al., 2011a,b; Wadl et al., 2011) and in other 15 countries (Rubino et al., 2011). Overall, it is assumed that this product was distributed from Egypt in 25 different countries (RASFF Portal, 2012b). A much larger foodborne outbreak as in Germany took place in China, in 2008. Approximately 294,000 children were affected and over 50,000 were hospitalized caused by contamination of milk with melamine (Ingelfinger, 2008). A good overview about the distribution of the contaminated milk and milk products with melamine from China is given in the 54 pages comprising tables of the European Commission (European Commission, 2008). These cases show that food and in particular also milk is prone to facilitating the spread of potential risks and allows quicker distribution of a biological agent than many other products, because it is according to Kaplan and coauthors (1962) an efficient vehicle for pathogens that may pose a substantial risk to human health and could affect a large number of consumers (Valeeva et al., 2005).

Generally, contaminations in the food supply chain can be distinguished into accidental[2] and deliberate[3] ones (Knutsson et al., 2011). According to Sobel et al., 2002 an intentional contamination on the food supply can 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 (Sobel et al., 2002).

However, in the case of an outbreak of a foodborne disease or animal diseases, decision-makers are often confronted with the difficulty of assessing the potential consequences of an outbreak (Dubé et al., 2009). In this context, modeling can be useful to assess the possible

[2] Further information about cases of milk contamination and numbers of foodborne outbreaks can be obtained from the detailed research articles by Ryan et al., 1987; Hennessy et al., 1996; Mead et al., 1999; Khan et al., 2001; Adak et al., 2002; Sobel et al., 2002; Rocourt et al., 2003; Stark, 2006; WHO, 2007; Duchowski et al., 2009.

[3] Details on the threat of intentional contamination as well as occurred incidents of intentional contamination are available in the studies by Kolavic et al., 1997; Török et al., 1997; Khan et al., 2001; Sobel et al., 2002; CDC, 2003; Manning et al., 2005; Yoon & Shanklin, 2007; Sobering, 2008 and by Veiga, 2011.

consequences of an outbreak and to inform decision-makers (Keeling, 2005; Garner et al., 2007). The first time epidemiologic models were used for the decision support during the foot-and mouth-diseases outbreak in United Kingdom, in 2001 (Keeling, 2005).

The aim of this chapter 2 and thus also of this thesis is to develop a simulation model in order to identify actors and flow of goods, which can promote the spread of a hypothetical contamination due to the trade connections or are vulnerable to contaminations in the milk supply chain. Furthermore, strategies to safeguard the milk supply chain are derived from the model results. To prepare a simulation model and therefore to achieve these objectives, it is necessary to conceptualize a conceptual model in the first step. The conceptual model comprises on the one hand an overview about the actors, the different trade structures between the actors and the other hand the operation rules of the milk supply chain. This topic is addressed in section (i).

In the following section (ii) trade structures are analyzed particularly with regard to the trade volume, number of trade partners, the geographical distances and the density of trade connections between trade partners in order to extend the knowledge about the milk supply system. This analysis focuses on the two main actors of the milk supply chain: milk producers and dairies. In this context, specific measures from network analysis are applied. These measures help to quantify the topology (Gampl, 2006) of the milk trade network and supply comparative information about the relevance of companies for the spread (Lentz et al., 2009). Data about the trade connections between these actors are available.

Based on the conceptual model a simulation model is set up, which includes all relevant objects from the conceptual model. The simulation model considers vertical and horizontal trade structures in the dairy industry. Vertical trade includes the milk distribution between milk producers, dairies, and consumers. Horizontal trade occurs between dairies that trade among each other to balance their over- or undersupply. Horizontal trade is therefore referred to as “inter-dairy trade”. In this section, it is hypothesized that the extent of inter-dairy trade significantly influences the spread of contaminated milk. To verify this hypothesis, it is necessary to extend the milk supply chain from section (ii) with the inter-dairy trade connections and the trade connection between dairies and consumers. Data about the trade connection of these actors are not available. By application of a gravity model, these missing links are generated so that the complete vertical and horizontal supply chain could be pictured. The hypothesis is tested using a computer simulation model predicting the spread of a contaminant via trade of milk and is given in section (iii). In this context, the simulated damage situation with regard to the virulence, resistance and vulnerability of the actors and the geographical range of a contamination is quantified (see section iii). These predictive information provide a first indication of relevant actors to safeguard the milk supply chain.

The last section (iv) deals with the question, how many relevant actors in the milk supply system should be selected for a contingency plan by decision-makers so that the damage situation could be avoided or minimized regardless of the flows of milk and with scant resources. This question should be answered on the one hand for the scenario that a deliberate introduction of a pathogen occurs into the supply chain of milk, especially on the scenario in which the milk producers serve as portals of entry and consumers of milk are the targets of the introduction. On the other hand, this question should be answered under the assumption that a possible attacker would like to reach a maximum spread of contaminated milk by a minimal number of milk producer nodes as portals of entry.

2.2 MATERIAL AND METHODS

This work is focused on the dairy product 'processed milk'. Processed milk (or drinking milk) is defined as raw milk, whole milk, semi-skimmed and skimmed milk (European Union, 2007). The main reason for concentrating on processed milk was that this commodity is a homogeneous product and no other flows of goods, e.g. additives, have to be considered. Further reasons are contained in manuscripts 5.1 and 5.2.

It is known that characteristics of the milk, the kind of biological agents or toxins, individual dispositions like the age of people (Crerar, 2000; Rocourt et al., 2003; McCabe-Sellers and Beattie, 2004; Liu et al., 2010) and internal processes like pasteurization (Bake et al., 2003; Riemelt et al., 2003; VO 853/2004; Zangerl, 2007; Franzen, 2009; Weingart et al., 2010), can influence on the one hand the inactivation or minimization of the virulence of a contagion and on the other hand the vulnerability of the consumer to a contamination (Pinior et al. 2012a,c). The influence of these aspects on the virulence and vulnerability is important, but beyond the scope of this thesis. In this thesis the focus is on the trade of processed milk.

A description of the material[4] and methods is presented in this section and it is divided into four segments (i-iv). In the following sections, the terms “milk supply system” and “milk supply chain” as well as “milk trade network” are used interchangeably.

i. Description of the milk supply chain (Conceptual model)

The first section includes the description of the milk supply system, which was carried out by a collection of information from the literature. The aim of this literature study was to capture the current state of knowledge about the actors and structures in the milk supply chain in Germany. In this context, the research was performed mainly by using scientific databases (ScienceDirect™, ISI Web of Knowledge™, and Google Scholar™).

[4] In general, all figures, which are shown in the entire thesis, were created either with the software OmniGraffle Professional (Version 5.4.2), MindNode Pro, or by using the visualization tool Cytoscape (Version 2.8.1). All statistical representations were prepared with DataGraph (Version 3.0) and Excel (2010). All presented maps of Germany were created by using the standard software Kartenexplorer (Version 2.03) provided by Federal Research Institute for Animal Health (FLI), Wusterhausen, Germany). The computer simulation model was set up using Python (Version 2.6.) and JAVA (JDK6).

ii. Analysis of the milk supply chain by using of the network analysis[5]

In the following sections (ii-iv) the milk supply chain was analyzed with the available data, which are summarized in Table 1.

Table 1. Utilized data with sources

Data	Source
Trade relations between milk producers and dairies (geographical resolution: on a country level)	BLE[1], 2010
Trade relations between individual milk producers and dairies	StMELF[2], 2004
Delivery quantity of milk from milk producers to dairies (geographical resolution: on a country level; delivery quantity was aggregated for one year)	BLE[1], 2010
Supply and demand related to the amounts on milk between dairies and between milk producers and dairies (amounts of milk: aggregated for one year)	BLE[1], 2010
Production capacity of the dairies per dairy product	BLE[1], 2010
Geographical position of the location of the dairies with their affiliation to individual milk producers	StMELF[2], 2004
Location of countries and communities	Federal Database[3], 2010
Inhabitants per community	Federal Database, 2010

[1] Data was provided by the Federal Office for Agriculture and Food (BLE) for the year 2010; Bonn
[2] Data was available at the Bavarian State Ministry for Nutrition, Agriculture and Forestry (StMELF) for the year 2004; Munich
[3] Data was used from the Federal Statistical Office Database for the year 2010

The underlying milk supply chain can be decomposed into three categories: milk producers, dairies, and consumers (Figure 4). These three categories had to be chosen, because the quality of the available data hampered a more detailed description of the actual trade structures. For example, data about the trade relations between milk producers and the dairies were available for the year 2010 with the limitation that the milk producers' locations were only available on the county level. All milk producers of a county were therefore aggregated into a single milk producer node (P). Due to the fact that dairies (D) deliver milk to different

[5] This section is partially published in the Journal on Chain and Network Science with authorization of the supervisor of this thesis according to the doctoral degree regulations of the 28th of August 1985 and 17th of June 2011 as well as following statutes of changes of the Agricultural Faculty of Bonn University – (see section 5.1 or list of publications Pinior et al. 2012a).

food retailers, we focused on the consumption of processed milk per consumer in a municipality instead on the (single) food retailers themselves (Figure 4). All consumers in a single municipality were aggregated to one consumer node (C).

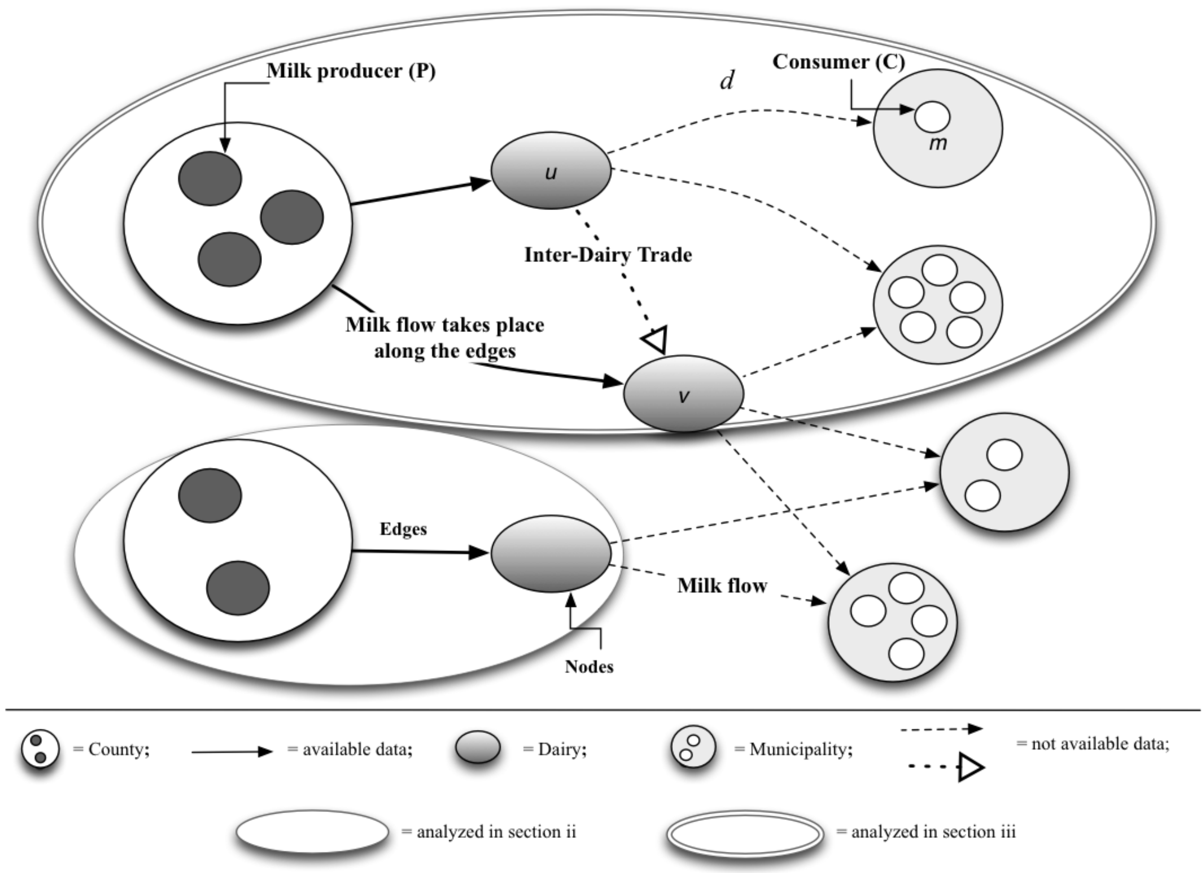

Figure 4. The underlying milk trade network (Abbreviations are defined in the text)

In this section (ii), we have used an approach from the graph theory in order to analyze the structure between milk producer nodes and dairy nodes in Germany with the available data.

Graph theory is a branch of topology and investigates patterns of relationships among pairs of objects (Kuper, 1987). It is a field in mathematical research (Chartrand, 1984; Diestel, 2006; Caldarelli, 2007; Barrat et al., 2008). The term network is used in graph theory and can be described by means of mathematical elements called graph (Caldarelli, 2007). General, the terms ‘chain’ and ‘network’ can be used interchangeably because chains can also be analyzed as a graph (Andersson et al., 2001; Gampl, 2006; Peña, 2011). The presentation of a graph can take place by an adjacency matrix[6] (*A)* (Caldarelli, 2007; Lentz et al., 2009). According to graph theory, a trade network (or graph) G= (V, E) consists of nodes V and edges E (Figure 4), where the nodes symbolize actors or companies and the edges represent the trade relations or connections between the actors (Newman et al., 2006; Lentz, et al., 2009; Lentz et al., 2011). In their entirety, the nodes and edges represent the trade network (Lentz et al., 2009; Natale et al., 2009). The flow of goods takes place along the edges and therefore also takes place between companies and can be distinguished by network theory as follows (Caldarelli, 2007; Lentz et al. 2009; Newman, 2011): a) directed or undirected and b) weighted or not weighted.

The underlying milk trade network is obviously directed (Figure 4), as the flow of goods in this network is always directed. The weighting of the edges can be done according to the trade volume or the distance between the nodes. Both weightings were used in order to analyze the milk trade network. In this context, all amounts of milk movements between milk producer nodes and dairy nodes as well as between dairy nodes were summed up for one year (Table 1). The distance (*d*) between any milk producer node *i* and dairy node *j* is thereby given as geographic distance (equation 1). This calculation of the distances between the individual milk producers and their associated dairies was only possible for 2004 because the locations of all dairies were only known for that year (Table 1). To calculate the Euclidian distance between milk producer nodes and dairy nodes, the geographic centroid of the county (Gauß-Krüger coordinates, Geo-3-bar code calculation (x*k*)) was used as the point of reference.

$$d_{ij} = \sqrt{\sum_{k=1}^{2}(x_{ik} - x_{jk})^2} \tag{1}$$

Graph theory provides certain measures which are suitable for the identification of central nodes (i.e. companies). Regarding the spread of a hypothetical contamination, companies are called central if they are suitable to promote the spread (Lentz et al. 2009) of a contamination or if they have a higher risk to be supplied with the contaminated goods. Central companies are distinguished from others by a high degree (Wasserman and Faust, 2009), e.g. in- and/or

[6] The matrix (A) indicates if node pairs (i, j) are interconnected. The elements of the matrix are 1, when a connection between nodes i and j exists and 0, if no connection between the nodes exists (more information about adjacency matrix are available by Ahuja et al., 1993; Caldarelli, 2007; Lentz et al. 2009; Newman, 2011).

out degree. Another measure considers the density of the trade connections between companies and is called edge density.

For brevity, in what follows, the degree centrality is one of the simplest centrality measures. It counts the number of incoming (in-degree) and outgoing (out-degree) trade connections of a company. Companies that are relevant for the spread of a contagion are characterized by a high out-degree (equation 2).

The out-degree (D_{out}) of a node *i* is the sum about the i-th line of the adjacency matrix (*A*). The matrix (*A*) indicates if node pairs i and *j* are interconnected (Lentz et al., 2009).

$$D_{out(i)} = \sum_{j=1}^{n} a_{ij} \tag{2}$$

Companies with a high in-degree also harbor a high risk potential, because they have an elevated chance to catch the contagion. Furthermore, the distribution of the degrees supplies relevant information about the structure of a network (Lentz et al. 2009) and also about food safety. Both the 2004 and the 2010 data include information on the countries where the dairy nodes purchased their milk. The out-and in-degree was calculated for the milk producer nodes and dairy nodes and allows to compare the degree-distribution of these actors for both years.

The density (*D*) of a network is a relative measure; it is calculated by the ratio of the actually existing number of edges (*E*) to all possible edges between the nodes (*V*) in a direct network (equation 3).

$$D = \frac{|E|}{|V|(|V|-1)} \tag{3}$$

The density of the milk trade network was determined by milk producer nodes and dairy nodes and was calculated for both years. The density of a network can take values between 1 (fully connected) and almost 0 (no edges). If the density of the network equals 1, all companies can reach any other company within one step.

iii. Application of a gravity model in order to set up the simulation model[7]:

In the next step the milk supply chain is extended through the objects consumer nodes and the trade between dairy nodes in order to depict the vertical and horizontal trade structures in the milk chain. On the one hand, the vertical flow between milk producer nodes, dairy nodes and consumer nodes (without inter-dairy trade) and on the other hand the horizontal flow of milk between dairy nodes (inter-dairy trade) is taken into account (Figure 4). As described in section (ii), all milk producers of a county were aggregated into a single milk producer node. A similar degree of aggregation was adopted for the category consumer. For the above mentioned extension of the milk supply chain, no data were available.

Missing trade links between dairy nodes and consumer nodes as well as between dairy nodes were generated by the gravity model. The gravity model (Anderson and van Wincoop, 2003) is 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 (Lewer and Van den Berg, 2008; Bikker, 2010). The concept is based on Newton's gravitation model (Baier and Bergstrand, 2009; Anderson, 2011) and in economic research a modified version of Newton's gravitation theory has been used to predict and explain trade flows (Bergstrand, 1985; Anderson and van Wincoop, 2003; Lewer and Van den Berg, 2008; Anderson, 2011). In this case, the two market actors are the dairy node on the one hand and the consumer node on the other.

The probability *q (u, m)* of a given dairy *u* delivering milk to the consumer node *m* is given by:

$$q(u,m) = q_0 * c(u) * h(m) * \frac{1}{d}(u,m) \tag{4}$$

where *c* is the production capacity of the dairy *u* and *h* is the number of consumers of consumer node (municipality) *m*. It is assumed that *h* is proportional to the demand of node *m*. The locations of the consumer nodes as well as the inhabitants per municipality are taken from the Federal Statistical Office Database (2010). The parameter *q0* was estimated by a local field investigation in the Federal State of Brandenburg. It was adjusted is such a way

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that each consumer node was served by six different dairies, on average. The geographical distance between dairy *u* and consumer node *m* is given by *d (u, m)*. Euclidian distances were calculated using the geographic centroid of the consumer nodes.

With respect to the inter-dairy trade of milk, two dairy nodes *u* and *v* trade with each other with the probability:

$$\rho(u,v) = \rho_0 * w^{+}(u) * w^{-}(v) * \frac{1}{d}(u,v) \tag{5}$$

where w^{+} / $^{-}$ denotes the supply and demand of two dairy nodes, and *d* the distance between them. Parameter ρ_0 determines the strength of the inter-dairy trade. Data on the supply and demand of processed milk was available (Table 1).

To analyze the impact of the inter-dairy trade, the parameter ρ_0 was varied.

For each figure of ρ_0 the following variables were determined

- the **virulence** of the milk producer nodes, which is the number of consumer nodes reachable from every milk producer node via the simulated trade network; milk producer nodes are **resistant** if no consumer node can be reached by them
- the **geographical range** of the milk producer nodes, which is the median distance between the milk producer nodes and consumer nodes and
- the **vulnerability** of the consumer nodes. This is the number of milk producer nodes from which a consumer node can be reached. Consumer nodes are **resistant** if they cannot be reached by a milk producer node.

Virulence and vulnerability are expressed as percentages of the total number of consumer and milk producer nodes respectively. For example, a virulence of p % indicates the percentage of consumer nodes which are contaminated by the contagion.

Due to the random nature of the model, we generated 500 networks for each parameter ρ_0 and used the respective median values for virulence, geographic range and vulnerability. Since ρ_0 was hard to interpret, it was substituted by the corresponding median number of inter-dairy edges (%). The variation of the parameter ρ_0 was used for sensitivity analysis and provided information on the stability of the gravity model.

For simulating the spread of a contaminant, we assumed that a contaminant present at a node is passed to another node with p= 1.0, if an edge exists between the nodes. Furthermore it was assumed that the milk producer nodes were the sources of the contamination. This model allowed to highlight the relation between inter-dairy trade on the one hand and virulence, resistant, geographic range and vulnerability on the other hand.

The influence of the inter-dairy trade was presented as a relative change of virulence, geographic range and vulnerability as compared to the baseline scenario with no inter-dairy trade.

However, in this simulation model we integrated 294 milk producer nodes, 80 dairy nodes and 12,223 consumer nodes. 80 dairies were included in the model, because the geographical locations, which are a parameter of the gravity model, were known for these dairy nodes for the year 2010. These 80 dairies got their milk from 294 different counties. Therefore, the model considers 294 counties, where raw milk was produced. The model includes 61.43% of the processed milk produced in Germany.

iv. Development of a contingency plan for decision-makers by the use of optimization algorithms[8]:

This section provides prescriptive information for decision-makers and is based on the underlying milk trade network in section (iii). Milk producer nodes should be identified, which are suitable to be included in a contingency plan set up to prevent or mitigate the consequences of deliberate contamination of a food supply chain. It is focused on the threat of a simulated deliberate introduction of a pathogen into the milk supply chain. Especially for a scenario, where the milk producer node is used as the portal of entry for a pathogen and where milk consumer nodes are the target of the attack (see source-target scenario in the study by Wein and Liu, 2005). It is assumed that a potential attacker would aim at reaching a maximum spread of the contaminated milk and at using a minimum number of milk producer nodes as portals of entry for the pathogen. Ideally, the attacker would aim at reaching the

[8] This section is partially submitted in a peer reviewed Journal with authorization of the supervisor of this thesis according to the doctoral degree regulations of the 28th of August 1985 and 17th of June 2011 as well as following statutes of changes of the Agricultural Faculty of Bonn University – (see section 5.3 or list of publications Pinior et al. 2012c). Moreover, this section was slightly modified.

maximal spread of contaminated milk by contaminating the first milk producer node in the network of milk trade. If the attacker was not stopped after the first assault, he will contaminate another milk producer node. He will choose a milk producer node with the largest increase in the number of infected consumer nodes. The attacker has achieved his goal, when all consumer nodes have been supplied with the contaminated milk. It is known that the portals of entry differ in terms of the damage caused, i.e. in terms of the number of consumer nodes reached. Possible variations in the trade links between milk producer nodes, dairy nodes and consumer nodes as well as between dairy nodes are considered. It is investigated how these trade links alter the selection of portals of entry.

The aim of this section is to provide the following information for decision-makers on the chosen scenario:

Firstly, which portal of entry would be chosen by a hypothetical attacker, if data on the commodity flows became publicly available? Secondly, how many portals of entry would the attacker have to choose to reach all consumer nodes with contaminated milk in Germany? Thirdly, in which sequence would an attacker choose potential portals of entry? Fourthly, are there milk producer nodes that can be selected independent from the flow of milk to induce maximum damage? Fifthly, 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 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 (Korte and Hausmann, 1978; Bouchet, 1987; Hüftle, 2006) and is applied under the predetermined objective function to find the most appropriate milk producer nodes (P) as portals of entry for a pathogen to cause maximum damage on the condition that maximum spread of contaminated milk in association with a maximum contaminated number of contaminated consumer nodes (C), so that the number of milk producer nodes involved in spreading the pathogen is minimal (equation 6).

$$\max \left|\{c\colon c \in C; \min|\{p\colon p \in P\}|, p \in D, c \in D, D \in R\}\right| \tag{6}$$

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 the model.

294 candidates 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 ordered set of selected candidates and s_i is a member of this ordered set at position *i*. Each member of the set is assigned a value $\Delta v(s_i)$. This value represents the additional weighted number of contaminated consumer nodes, when the milk producer node *s* is added to the set of solutions. The weight ($w_i = i^{-1}$) depends on the position (*i*) of the milk producer node in the ranked list of solutions ($i = 1, \ldots, n$). With respect to the objective function, a milk producer node is only added to the list when the following condition (equation 7) is fulfilled:

$$S_{i+1} > S_i \text{ with } S_i = \sum_{i}^{n} \Delta v(s_i w_i) \tag{7}$$

Therefore, the greedy algorithm searches for the "best" milk producer node according to the number of contaminated consumer nodes, sets this milk producer node on the first position in the list of potential portals of entry and then follows with the "next-best" milk producer node (Figure 5). As a consequence, every place in the list can be filled by only one milk producer node. The greedy algorithm cannot handle the theoretical case where two milk producer nodes have exactly the same value and should therefore occupy the same place in the list of potential portals of entry. The algorithm stops when S_i cannot be improved any more or, in other words, when all consumer nodes are contaminated (Figure 5). The scenario, in which all consumer nodes are reached, represents a worst-case situation. The greedy algorithm was applied for two kinds of milk trade networks, one with inter-dairy trade (with random contacts between dairies) and one without. Two contingency plans over 50 simulations for each kind of the milk trade network were emerged. One simulation represents one sub-trade network.

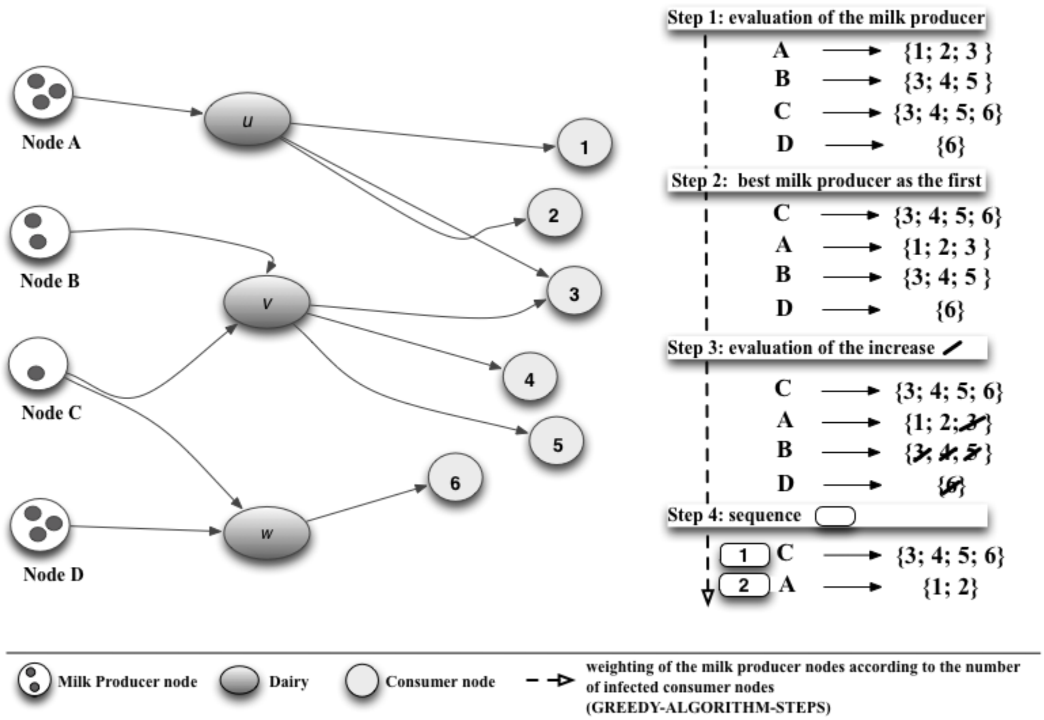


Figure 5. Steps of the greedy algorithm (without inter-dairy trade):

Step (1) Contamination of a milk producer node and calculating the number of consumer nodes that can be hypothetically contaminated (absolute); Step (2): Selecting the milk producer nodes that have reached the maximum number of consumer nodes. The milk producer node with the maximum number of infected consumer nodes was used as a baseline for further evaluations of milk producer nodes; Step (3): Select the second-best milk producer node, on the condition that it has infected other consumer nodes than the first milk producer node (maximum increase for the first milk producer node); Step (4): Sorting the milk producer nodes according to extent of damage leading to a rank-order of the milk producer nodes in the contingency plan.

To answer the question, whether milk producer nodes can be used regardless of the flow of milk as appropriate portals of entry for a pathogen, a comparison between the two contingency plans according to the most commonly observed portals of entry was conducted. To achieve a better comparison between the milk producer nodes, which may occur in both contingency plans, and those, which are only included in one of the contingency plans, the impact of these milk producer nodes for the damage situation was determined with equation 8.

$$I_{(p)} = \sum_{i=1}^{r} h(r) * g(r) \tag{8}$$

The impact of milk producer nodes *I(p)* is calculated using its rank *(r)* (position) in the ordered contingency plan determined by the greedy algorithm for each of the considered random networks. Let *h(r)* be the frequency of *(p)* at position *(r)* using all simulation results, where *g(r)* is a weight, *g(r) = (r+1)-i*. The value of *r* is determined by the greedy algorithm and resembles the maximum size (length of the contingency plan) of the best ordered milk producer nodes in random network considered.

In order to verify if our results represent the optimal solution we have used a further optimization algorithm, the genetic algorithm. In this context, it was investigated whether the genetic algorithm finds a fewer number of milk producer nodes, which can introduce a worst-case situation. The genetic algorithm is used, similar to the greedy algorithm, for solving optimization problems. The main difference between the greedy algorithm and the genetic algorithm is that genetic algorithm calculates and evaluates the number and rank order for combinations of milk producer nodes, while the genetic algorithm evaluates the individual milk producer nodes, both regarding their damage situation. In this context, the genetic algorithm stops as well as the greedy algorithm when all consumer nodes are contaminated through the milk producer nodes.

One disadvantage in the application of genetic algorithm is the high computational effort for the evaluation of combinatorial solutions (Hüftle, 2006). For this reason, the minimum selected number of milk producer nodes from the greedy algorithm calculation was used as a starting point for the optimization calculation for the genetic algorithm. The numbers of all possible combinations of milk producer nodes, which must be considered for the genetic algorithm calculation, are described in Equation 9.

$$\binom{N}{n} = \frac{N!}{n! * (N-n)!} \tag{9}$$

The variable *N* represents the total number of milk producer nodes (*N*= 294) and *n* is the determined minimum number of milk producer nodes from the greedy algorithm calculations.

2.3 RESULTS

These results are based on published and submitted manuscripts. The results presented here were copied literally or slightly modified from the manuscripts. If these results are cited, the specifications of the journals must be given. The results of "the description of the milk supply chain and analysis of the milk supply chain by using of the network analysis" were published in the Journal Chain and Network Science (see chapter 5.1). The results of "the simulation model" were published in the Journal of Dairy Science (see chapter 5.2). The results of "the management plan" are under review (see chapter 5.3).

i. Description of the milk supply chain (Conceptual model)[9]

This description of the milk supply chain concentrates on the trade structures and the trade actors in the German dairy industry as they existed in 2010.

There were 220 dairies that processed 96.8% of the raw milk in the country (BLE, 2011). Cooperative and private dairies could be distinguished (Wegmeth, 2002; Wienert, 2008; BKartA, 2009; Hellberg-Bahr et al., 2010). Cooperative dairies were owned by milk producers and processed 70% of the milk in Germany (Hellberg-Bahr et al., 2010). 4.9 million cows formed the basis of the German dairy industry in 2010. Of these, 4.1 million were used for milk production (Destatis, 2010). A total of 93,497 milk producers kept these cows (Figure 6a), which yielded 29.6 million tons of raw milk (Destatis, 2010; BLE, 2011). Usually the contract duration between a milk producer and a dairy is two or three years (Spiller and Schulze, 2006).

An average of 77,000 tons of raw milk was processed daily as commodities (Top Agrar, 2010). According to the analysis of the Bundeskartellamt 2009 (BKartA), dairies obtained raw milk from the milk producers over an average distance of 150 km. The longest noticed distance between milk producer and dairy was 425 km, the shortest 60 km. Raw milk was either collected by dairies that had their own fleet of tank trucks or by the use of external

[9] This section is published in the Journal on Chain and Network Science with authorization of the supervisor of this thesis according to the doctoral degree regulations of the 28th of August 1985 and 17th of June 2011 as well as following statutes of changes of the Agricultural Faculty of Bonn University – (see section 5.1 or list of publications Pinior et al. 2012a). Moreover, this section was slightly modified and supplemented by an illustration.

carriers (Anonymous, 2011; MIV, 2012). The latter allows dairies to outsource potential risks (e.g. product traceability) and costs (e.g. minimization of transport costs), but also management issues such as the fluctuating quantity of milk during the year (Anonymous, 2011). One way to reduce transportation costs is to optimize the milk collection frequency (MIV, 2012).

In addition to the direct trade connections between milk producers and dairies, there were also indirect trade connections through interconnected actors, e.g. business partners, such as other national dairies that sell and buy milk (Figure 6a). This trade among dairies adjusts for imbalances in the capacities of the dairies. To this end, both raw and processed milk was traded. Another indirect trade connection existed in the commodity flow following the processing level. By-products, for example whey, could be transported back to the farms as animal feed. Another backflow took place through so-called “retours”. These consisted for example of broken or wrongly ordered merchandize that was either returned to the dairies and handled as merchandize to be melted or not returned to the dairies and removed from the production circuit. Furthermore some dairies have integrated pure business enterprises into their supply chain to resell raw milk or dairy products nationally or internationally. These milk dealers were intermediaries that formed connections to other supply chains of other companies. In this context, the dairies, the processing industry as well as the milk dealers were actors on this market (BKartA, 2009). The spot market offers another marketing possibility to the milk producers. On the spot market, milk producers can sell the milk for the current price (Figure 6). This allows them to sell a short-term production excess in raw milk or residual quantities at the current milk price. The percentage of milk traded via the spot market was estimated as 0.03% of the total milk production. Offering milk on the spot market is connected with a selling risk for milk producers (Hellberg-Bahr et al., 2010).

Two more commodity flows exist on the producer level: 3.2% of the total production was not processed in dairies. It was either used for feed (2.7%) or directly marketed (0.2%; BLE, 2011). After processing, the finished dairy products were sold to food retailers, the food or pharmaceutical industry, the wholesale industry, schools, old people's homes, hospitals and canteens (BKartA, 2009). About 90% of the dairy products are distributed via 140 storage centers (MIV, 2012). A special consumer of dairy products is the food retail industry, which markets about 40% of the dairy products produced in Germany (BKartA, 2009). Discounters sold about 54% of these 40% of the products. About 44% of the total production was exported and 16% distributed via the channels of sale mentioned above (BKartA, 2009). The selection of trade partners between the milk producers and dairies, between different dairies as well as between dairies and food retailers is determined by many economics factors. Pinior et al., (2011) have shown by using the literature research, which factors play a key role for the choice of trading partners in the dairy industry (Figure 6b).

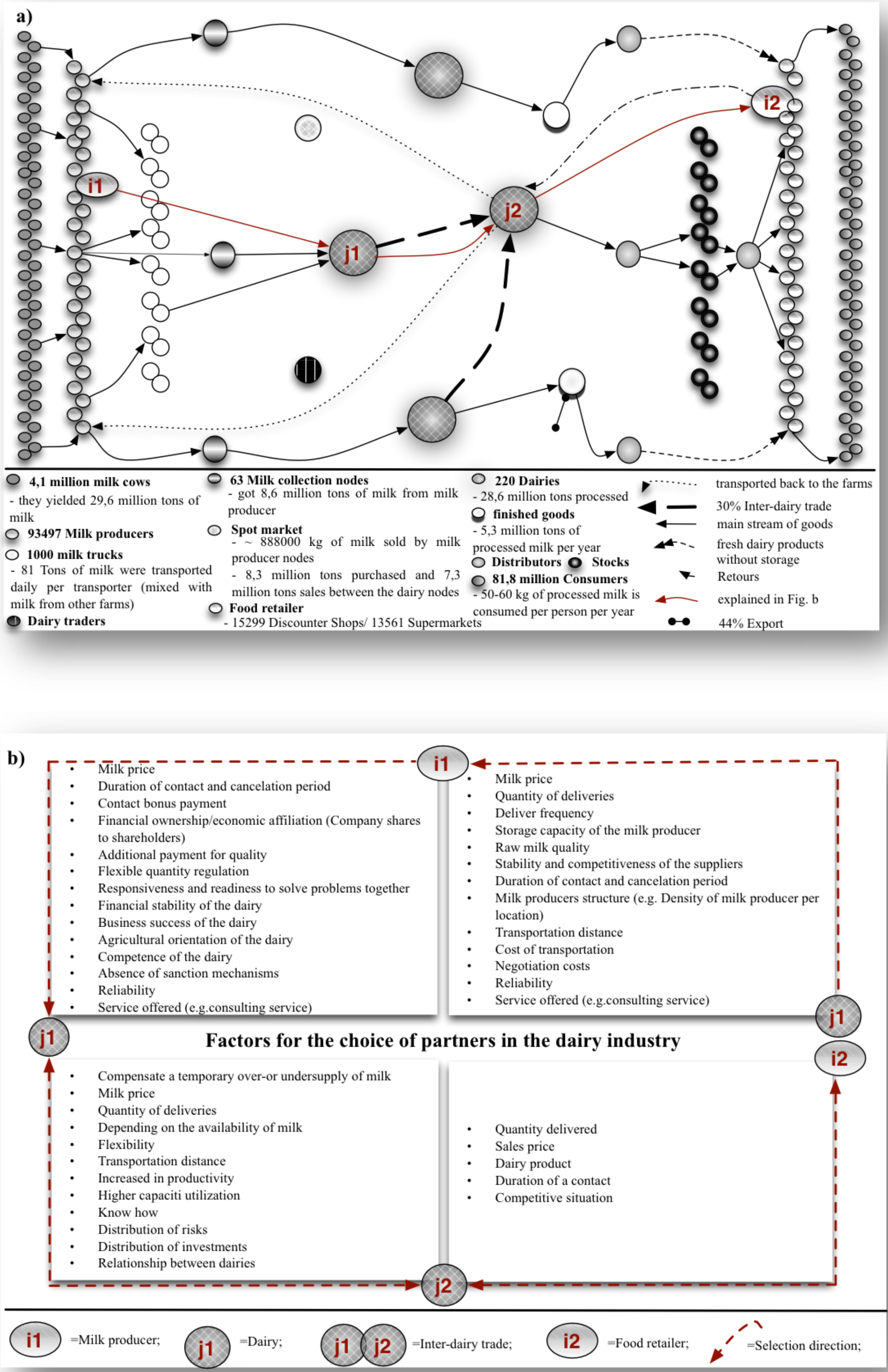


Figure 6. (a) The milk supply chain; (b) Overview about the economic factors for the choice of partners in dairy industry, Source: According to the literature research (see Appendix) by Pinior et al., 2011.

ii. Analysis of the milk supply chain by using of the network analysis[10]

Figure 7 shows the analyzed milk trade network for the years 2004 and 2010. The trade network comprised a total of 712 nodes in 2004 and 545 nodes in 2010. In 2004, the milk trade network consisted of 327 dairy nodes and 106,963 milk producers situated in 385 different counties. The maximum number of milk producers that sold milk to a single dairy node was 9,394 (8.7%) and 269 of all dairy nodes bought their milk from 20,050 (18.7%) milk producers. Analysis of the 2004 data showed that one dairy is supplied on average by 327 milk producers. In 2010, there were 220 dairy nodes and 325 different milk producer nodes. 136 of the 220 dairies got their raw milk from milk producer nodes. 85 of these 136 dairies produced processed milk. In 2004, the maximum in-degree of a dairy node was 62, and the median in-degree was 3. In 2010, the maximum in-degree of a dairy node was 49 and the median degree was 4.5. The maximum out-degree of a milk producer node was 20. Out of all dairy nodes, 34% had an in-degree of 1. The milk trade network in 2004 consisted of 1,938 trade connections between milk producer nodes and dairy nodes, which is 53% higher than the number of trade connections between milk producer nodes and dairy nodes in 2010 (1,042 trade connections). The milk flows between the milk producer nodes and the dairy nodes represent 0.38% and 0.49% of all directed edges (edge density) in 2004 and 2010, respectively. The trade connections were weighted according to the trade volume and the distances between the nodes: in 2010, the maximum quantity of milk delivered by a milk producer node to a dairy node was 0.23 million tons. The lowest quantity of milk delivered was 0.1 ton. Purchase and sale between dairy nodes represented 30% of the total milk production in Germany. In 2010, the maximum quantity purchased by a dairy node was 1.5 million tons and the maximum quantity sold was 2.7 million tons of milk. The minimal quantity purchased by a dairy node was 21 tons and the minimal quantity sold was 3.2 tons. Out of the 220 dairy nodes, 195 traded among each other. In this context, around 20% of all dairy nodes represented pure purchasers and 14% pure sale companies. 54% of all dairy nodes purchased and sold milk in 2010. Approximately half (97) of these 195 dairy nodes produced processed milk.

[10] This section is published in the Journal on Chain and Network Science with authorization of the supervisor of this thesis according to the doctoral degree regulations of the 28th of August 1985 and 17th of June 2011 as well as following statutes of changes of the Agricultural Faculty of Bonn University – (see section 5.1 or list of publications Pinior et al. 2012a). Furthermore, this section was slightly modified and presents only a part of the published results.

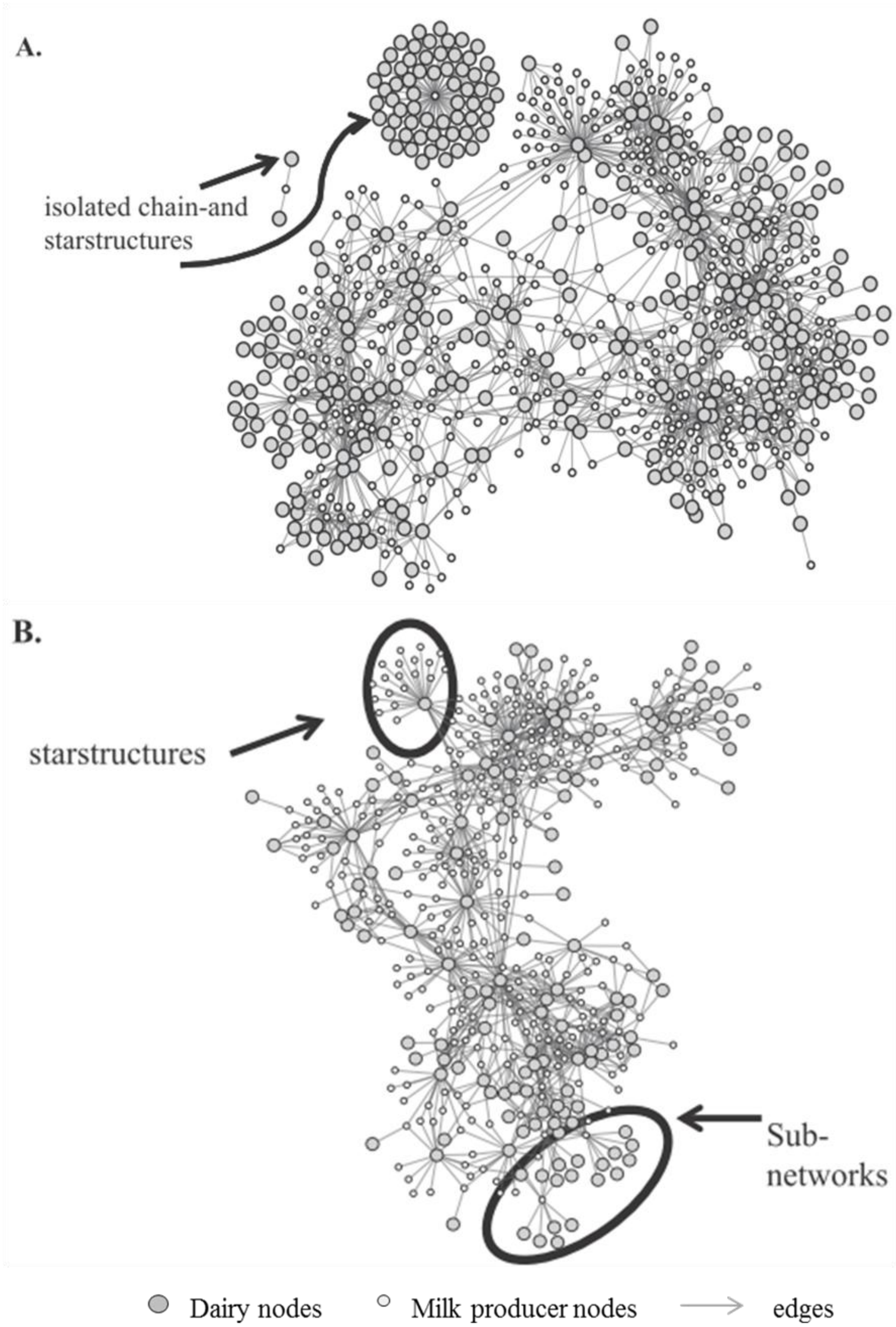


Figure 7. Visualization of the milk trade networks in Germany: the nodes represent the companies and the edges the trade connections between the companies (the position of the nodes does not correspond to the geographic location of the companies); a) trade connections between the milk producer nodes (counties) and dairies with whom contracts existed in 2004; b) trade connections between milk producer nodes (counties) and dairies with whom contracts existed in 2010.

An analysis of the distances between individual milk producer nodes and dairy nodes showed that milk producer nodes were on average 68 km away from the dairy nodes with whom contacts existed in 2004 (Figure 8).

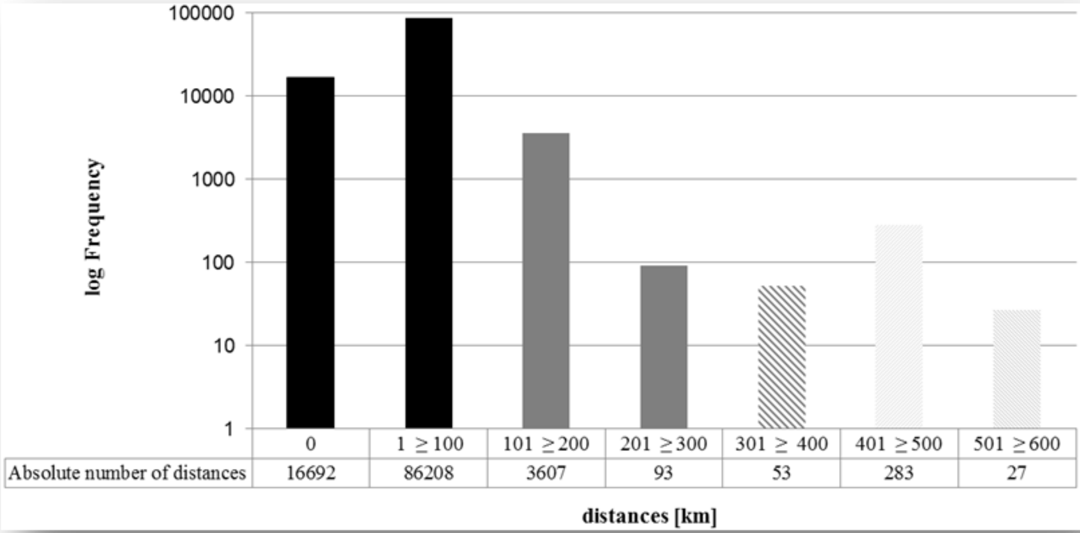


Figure 8. Frequencies of the distances between milk producer nodes (individual milk producer) and dairy nodes with whom contracts existed in 2004.

Based on the locations of 327 dairy nodes and 106,963 milk producers, the maximum distance was 557 km and the minimum 0 km (Figure 8). The majority of the milk producer nodes (96%) was located within a distance of 0 and 1≥100 km to their related dairy node.

iii. Simulation Model[11]

We hypothesize that the extent of inter-dairy trade significantly influences the spatial spread of contaminated milk and the contamination risk.

The spread of a contamination was simulated on a trade network comprising 294 milk producer nodes, 80 dairy nodes, and 12,223 consumer nodes. The milk trade network contained 73,338 edges. It included 90.4% of milk producer nodes in Germany, 58.8% of the

[11] This section is published in the Journal Dairy Science with authorization of the supervisor of this thesis according to the doctoral degree regulations of the 28th of August 1985 and 17th of June 2011 as well as following statutes of changes of the Agricultural Faculty of Bonn University – (see section 5.2 or list of publications Pinior et al. 2012b).

dairy nodes that buy milk from milk producer nodes, and 94% of the dairy nodes that produced milk. The network contained 98% of all consumer nodes.

With increasing of inter-dairy trade, virulence also increased (Figure 9a). Concerning the baseline scenario with no inter-dairy trade present (inter-dairy edges = 0%), the median virulence was 24% (50% confidence interval (CI): 15-35%; 95% CI: 0%, 56%). Inter-dairy trade influences median virulence as well as its variability. With increasing inter-dairy trade, virulence (median) increases monotonically in a nonlinear way (Figure 9a, solid line). The increase is rather steep with a slight increase of inter-dairy trade up to 1%. The curve flattens when inter-dairy trade is above 1% and reaches its upper limit (80%) when inter-dairy trade is about 4%. If the 50 and 95% CI of virulence are taken into account, it becomes evident that the virulence of 97.5% milk producer nodes is under 80% if inter-dairy trade amounts to 2%. If inter-dairy trade equals 3.5%, the lower limit of the virulence leaves the 0% limit. A further increase increases the lower limit to about 20%, stays constant until inter-dairy trade reaches 6%, and approaches a virulence of 80% when inter-dairy trade is above 7%. The same is true for the lower limit of the 50% CI, which increases steeply when inter-dairy trade is larger than 1%.

It should be noted that 7 out of 294 milk producer nodes are not involved in the spread (resistant) of the contagion if the inter-dairy trade is 0% (illustrated by the gray color in Figure 9b, map 1). Maps 1 to 3 in Figure 9b portray the virulence of the 294 milk producer nodes (counties). The area of those counties, for which the virulence could not be determined, is shown by a diagonal hatch pattern in maps 1 to 3. In this context, the influence of inter-dairy trade is presented as a relative increase of virulence (represented as a factor increase of the virulence) compared with the baseline scenario with no inter-dairy trade in maps 2 and 3.

The highest increase of virulence, by a factor of about > 73, was associated with only 2 milk producer nodes (Figure 9; map 2). On average, the relative increase of virulence for the milk producer nodes was by a factor of 4.2. However, the relative virulence of the milk producer nodes increased by factors between 0.9 and 83.5 compared with the virulence of the baseline scenario (Figure 9b; map 2).

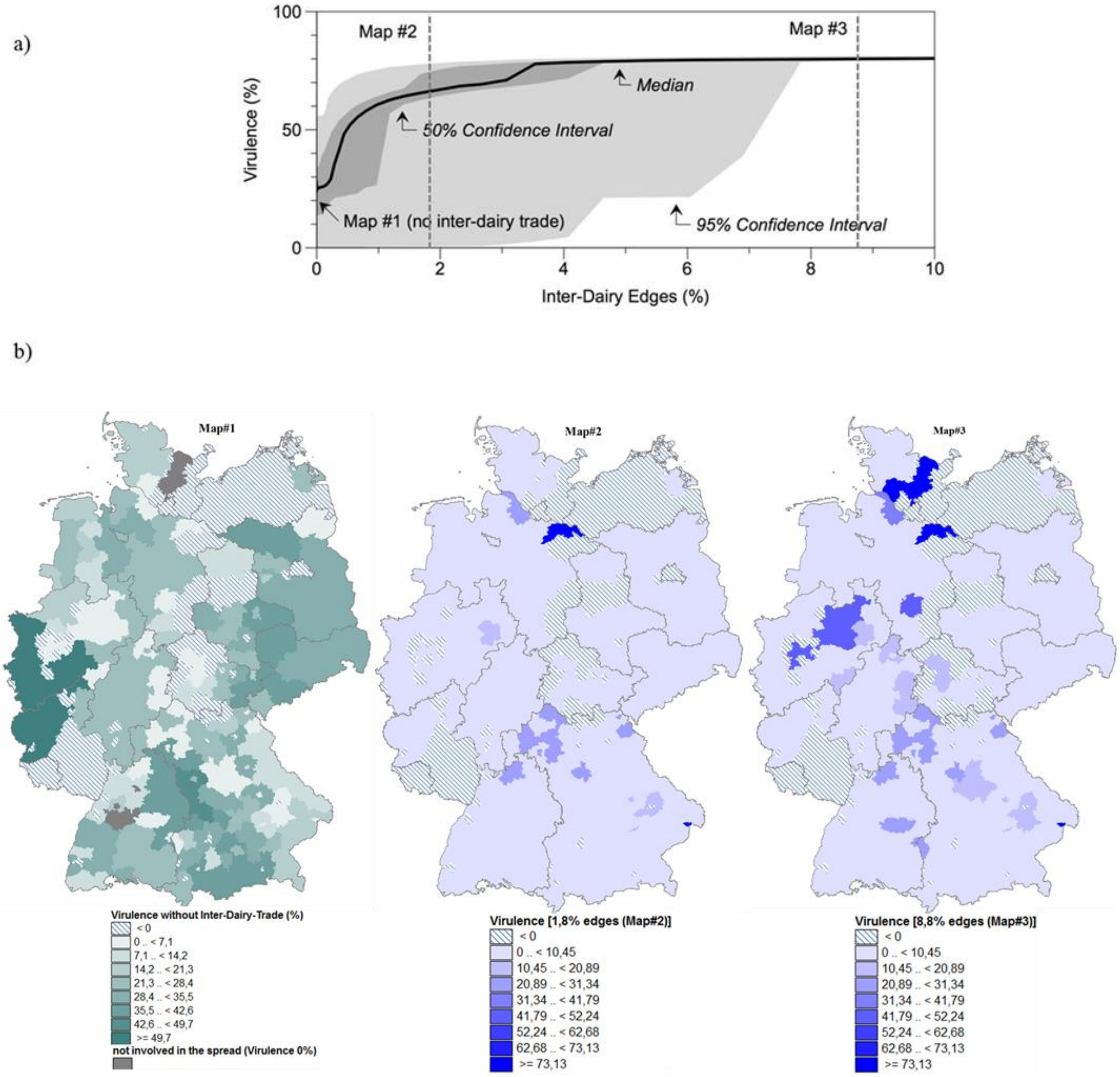


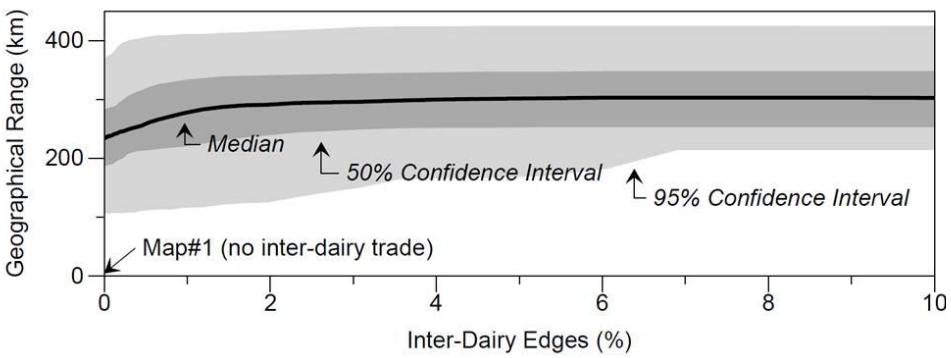
Figure 9. Virulence of milk producer nodes without (map 1) and with inter-dairy trade (maps 2 and 3) in Germany. The quantitative influence of the inter-dairy trade is presented as (a) relative change of virulence values; and (b) mapping of virulence values, in which the diagonal hatch pattern indicates geographical areas and those counties for which the virulence could not be determined. The main reason was that only 325 of 413 existing counties had a direct supply relationship to the dairies; 294 of these 325 counties were considered in our model, because we considered only those counties that had a trade relation to the 80 dairy nodes that produced milk. The milk producer nodes originating from the counties not considered in the model represent the diagonal hatch pattern in maps 1 to 3 and therefore these nodes have a negative factor increasing from <0 (i.e., the virulence could not be determined).

Figure 10a shows the quantitative influence of inter-dairy trade presented as the relative change of mean geographical range of milk producer nodes with regard to the spread of a contaminant. The map in Figure 10b portrays the geographical range of the contaminant for 294 milk producer nodes (counties). Contaminated milk was transported over distances ranging from 0 to 432 km (Figure 10b). Seven milk producer nodes, which are not involved in the spread of contaminations, had a geographical range of 0 km (shaded in gray, Figure 10b). The average geographical range of a contaminant was 234 km when inter-dairy trade was 0% (Figure 10a; map 1). Furthermore, no clear correlation existed between the type of virulence of the milk producer node and the geographical range of a contagion without inter-dairy trade. The correlation of the virulence with the geographical range was low (R^2= 0.26).

If inter-dairy trade was considered, the mean geographical range increased compared with the baseline scenario. In this context, the increase of the mean geographical range was flat, with a slight increase of inter-dairy trade up to 1%, it flattened when inter-dairy trade was above 1%, and reached its upper bound (300 km) when inter-dairy trade was about 2% (Figure 10a). Additional increases of inter-dairy trade did not lead to further substantial increases of the median and the 50% CI (Figure 10a). Furthermore, if the inter-dairy trade was below 1%, the mean geographical range of a contamination ranged between 118 and 388 km for 95% of the milk producer nodes (Figure 10a).

Maps 1 to 3 in Figure 11b show the vulnerability of the 12,223 consumer nodes (municipalities) in Germany. In the baseline scenario (Figure 11b; map 1), 14.5% of all consumer nodes were not supplied with contaminated milk. Therefore, these nodes have a vulnerability of zero (resistant), which is illustrated by the grey shading in map 1. Overall, 1.09% of the consumer nodes had a vulnerability of over 85%. The maximum vulnerability of 2 consumer nodes was 97%. This means that 2 consumer nodes were supplied by 97% of all milk producer nodes and therefore these nodes had a higher potential risk to be supplied with contaminated milk (Figure 11b; map 1). Overall, 15.4% of the consumer nodes had a vulnerability of over 50% (Figure 11a; map 1). About half of all consumer nodes (50% CI) had a vulnerability ranging between 8% and 39%.

a)



b)

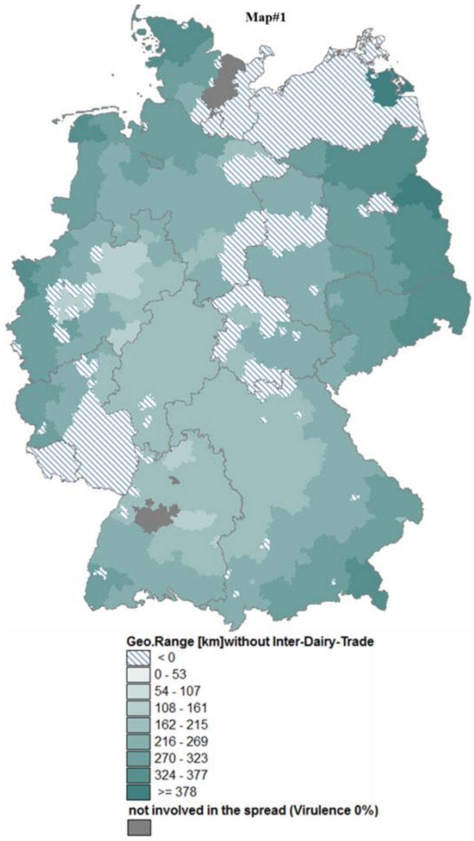


Figure 10. The geographical range (km) of milk contamination. (a) Quantitative influence of the inter-dairy trade shown as the relative change of mean geographical range values of milk producer nodes with regard to the spread of a contamination; (b) graphical representation of the geographical range values, in which the diagonal hatch pattern indicates geographical areas and those counties in which the virulence and therefore the geographical range could not be determined. Seven out of 294 milk producer nodes were not involved in the spread of the contaminant if the inter-dairy trade was 0% (illustrated by the gray color in Figure 10b, Map 1).

Figure 11a shows the quantitative effect of the increase in inter-dairy trade on vulnerability. The inter-dairy trade influenced the median vulnerability. The increase was steep, with a slight increase of inter-dairy trade up to 1%, flattening when the inter-dairy trade was above 1%, and approaching asymptotically its upper bound (more than 95%) when inter-dairy trade was about 4%. If the inter-dairy trade was below 3.5%, the 50% CI of the vulnerability covered a wide range of 8 to > 90%.

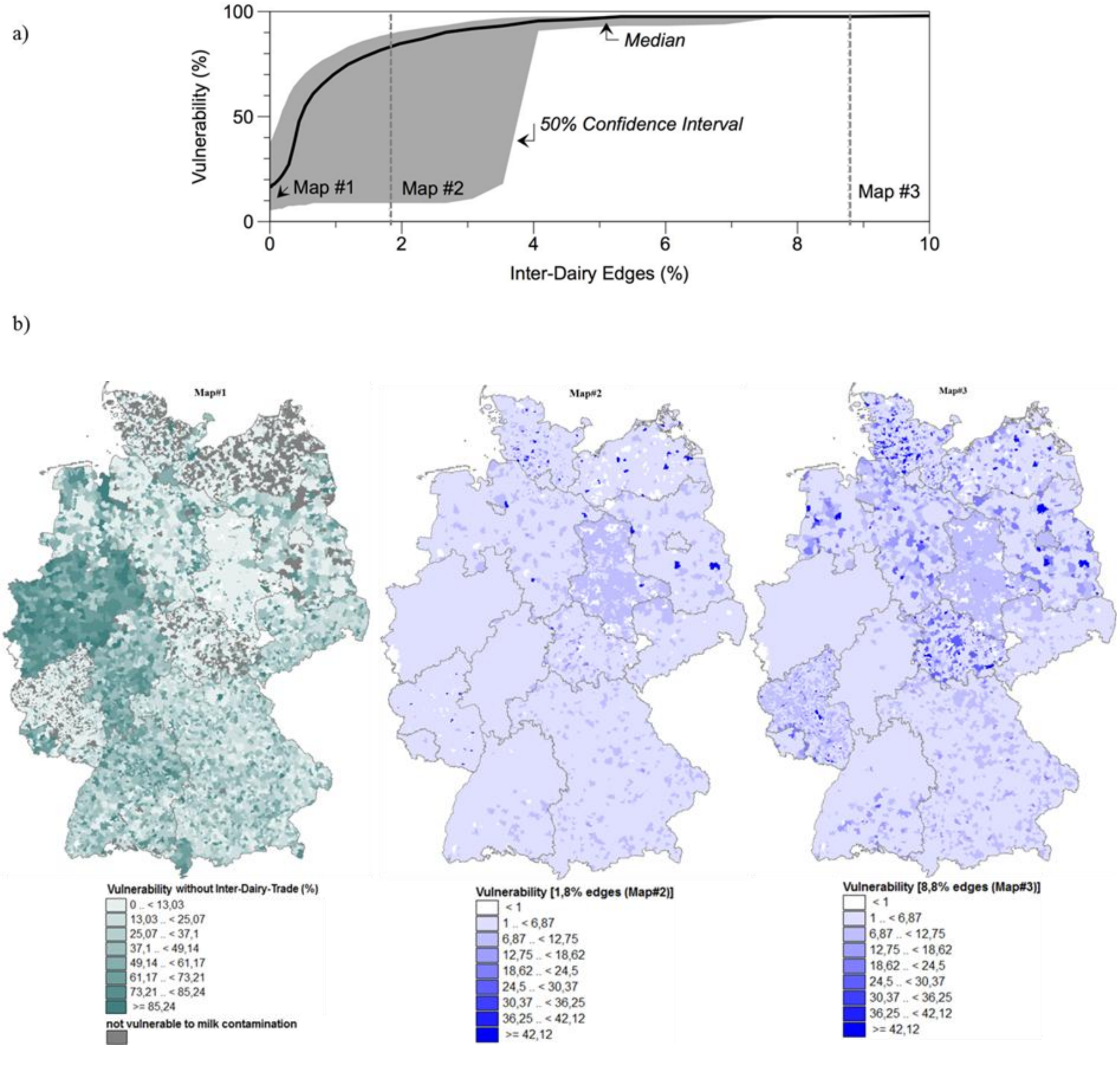


Figure 11. Vulnerability of consumer nodes without and with inter-dairy trade in Germany. (a) Quantitative influence of the inter-dairy trade shown as a relative change of median vulnerability values of consumer nodes with regard of the spread of a contamination; (b) graphical representation of the vulnerability values. In total, 14.5% of all consumer nodes were not supplied with contaminated milk (illustrated by the gray color in Figure 11b, Map 1).

Furthermore, inter-dairy trade values of > 3.5% led to an adjustment of the 50% CI of the vulnerability to the median and therefore the dispersion of the vulnerability values minimized. The majority of consumer nodes (71.65%) had an increase in vulnerability of a factor of > 1 to 6.87 (Figure 11b; map 2). The minimal increase was a factor of 0.09, the maximum was 48, and the mean increase a factor of 3.4 compared with the baseline scenario (map 2).

An increase in inter-dairy trade to 8.8% led to a maximum increase of vulnerability values by a factor of 191 (map 3; Figure 11); this applied to 0.5% of consumer nodes. Eighty percent of consumer nodes had a median vulnerability with factors ranging between 0.09 to 10 compared with the vulnerability of the baseline scenario (Figure 11a; map 3). The median increase of the vulnerability of all consumer nodes was a factor of 6.9 (Figure 11a; map 3).

iv. The contingency plan[12]

The contingency plan includes the number and rank-order of milk producer nodes for inducing the maximum damage situation as well as the associated number of contaminated consumer nodes (Figure 12 and 13) for the two kinds of trade networks (with and without inter-dairy trade). In Figures 12b and 13b, each line represents a simulation process of a total of 50 simulations. Each line represents the number of milk producer nodes which are involved in the worst-case situation per simulation. Furthermore, each column shows the rank of the milk producer nodes for the worst-case situation according to the reached number of consumer nodes. Figures 12a and 13a depict the damage situation in respect to hypothetically contaminated consumer nodes in association with the rank-order of the milk producer nodes.

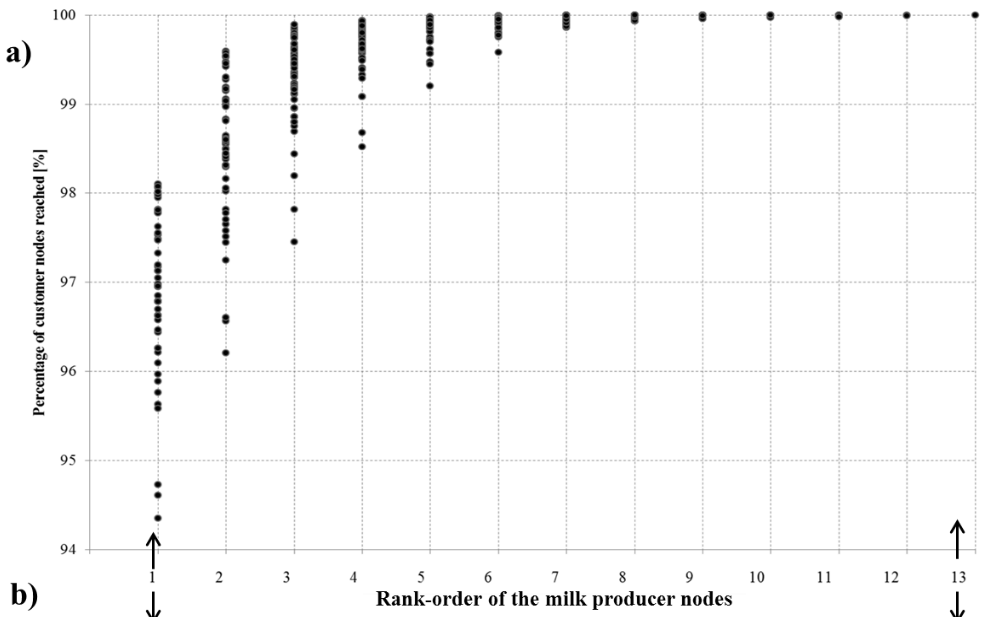
When the inter-dairy trade structures are taken into account, the entire contingency plan includes 86 (29.2%) different milk producer nodes from a total of 294 (100%). For all 50 simulations, the greedy algorithm calculated that the minimum required number of milk producer nodes to achieve the worst-case situation was seven and that the maximum number of milk producer nodes was 13 (Figure 12b). On average, by the introduction of a pathogen into nine milk producer nodes a worst-case situation can be induced. More than 94% of the consumer nodes could be contaminated upon introduction of the pathogen into the milk producer nodes on the first rank of the contingency plan (Figure 12b). The milk producer

[12] This section was submitted in a peer-review Journal with authorization of the supervisor of this thesis according to the doctoral degree regulations of the 28th of August 1985 and 17th of June 2011 as well as following statutes of changes of the Agricultural Faculty of Bonn University – (see section 5.3 or list of publications Pinior et al. 2012c).

nodes on the second rank led to a further increase of the damage situation of 1 to 2% (Figure 12a). All subsequent milk producer nodes induce a minimal increase in the number of contaminated consumer nodes by 1 to 4%.

One milk producer node (ID: 294) was identified in 49 out of 50 simulations (Figure 12b). Two milk producer nodes (ID: 66 and 500) showed up in 89% of all simulations. The remaining 83 milk producer nodes appeared on average 3.6 times in the simulations. In all simulations, 27 different milk producer nodes appeared only once (Figure 12b).

One milk producer node (ID: 294) was on the first rank in 26 of 50 simulations (Figure 12b). In all remaining simulations, this milk producer node ranked second (n=13) or third rank (n=10) in the contingency plan. Such "direct neighborhood" ranking of milk producer nodes in the contingency plan was observed for 68 (79.1%) nodes in all simulations (Figure 12b).



b)

	1	2	3	4	5	6	7	8	9	10	11	12	13
S_1	252	294	299	509	518	14	66	500	26				
S_2	294	297	299	511	14	519	500	66	444	120			
S_3	294	297	11	14	527	66	273						
S_4	294	61	143	505	467	5	519	203	66				
S_5	294	61	467	517	155	500	273	66					
S_6	512	294	299	39	303	15	519	66	500	444			
S_7	294	512	98	75	268	14	120	66	500				
S_8	294	512	2	3	66	120	26						
S_9	513	294	299	2	57	14	66	500	273				
S_10	252	294	8	44	1	14	66	120	500				
S_11	294	252	464	21	519	500	66						
S_12	100	513	294	31	83	511	29	500	66				
S_13	513	294	68	299	3	66	500						
S_14	100	252	294	402	233	39	3	66	500	120	444		
S_15	252	294	33	15	77	516	66	444	500				
S_16	294	297	83	509	14	516	66	500	120	489	240		
S_17	297	294	44	510	29	83	3	500	66				
S_18	294	252	510	14	110	500	66						
S_19	100	297	294	300	153	299	66	500					
S_20	100	297	294	4	299	148	468	3	500	240	66	120	
S_21	100	297	520	505	514	2	3	66	273	120			
S_22	294	512	31	59	15	176	500	66					
S_23	61	294	555	299	6	120	66	500	328	26			
S_24	294	252	467	6	4	152	444	120	66				
S_25	294	513	300	510	15	500	120	154	66	444			
S_26	100	252	294	299	231	303	6	519	66	500	120		
S_27	294	80	299	33	3	31	66	120	528	500			
S_28	294	252	11	39	233	401	66	500	6				
S_29	512	294	299	6	500	120	77	66					
S_30	294	252	44	299	232	66	120	500					
S_31	294	252	299	68	66	500	431						
S_32	294	297	555	299	203	500	240	66					
S_33	294	512	148	231	98	66	444	500					
S_34	100	61	294	505	39	14	515	240	500				
S_35	294	512	4	299	233	500	489	66					
S_36	100	61	294	2	500	120	66						
S_37	294	297	222	299	57	500	66	120					
S_38	294	61	222	299	511	6	500	66					
S_39	100	61	294	299	232	517	120	500	489				
S_40	297	294	106	110	86	203	500	273					
S_41	100	512	294	300	17	299	5	444	66	499	500		
S_42	294	297	555	299	6	500	431						
S_43	294	297	110	299	1	468	66	6	500	444			
S_44	294	61	83	509	326	555	15	66	120	444	47	73	500
S_45	297	294	4	153	59	6	66	500					
S_46	294	61	31	152	3	500	120	66					
S_47	100	252	294	555	150	273	240	66					
S_48	294	252	2	299	33	66	444	500	120				
S_49	61	294	464	1	45	14	120	66	500	273			
S_50	513	294	299	555	59	6	66	444					

Figure 12. Contingency plan taking inter-dairy trade into account in association with the hypothetically contaminated consumer nodes. a) Size of the damage situation with respect to the number of hypothetically contaminated consumer nodes per rank-order of the milk producer nodes. Each point represents the damage caused by a milk producer node in the underlying column of 12b). b) Results of a total of 50 simulations. Each line shows the number of milk producer nodes that are involved in the worst-case situation per simulation; each column shows the rank-order of the milk producer nodes for the worst-case situation according to reached number of consumer nodes. The milk producers on the first rank caused the maximum damage situation. The milk producer nodes on the second place caused the largest increase of infected consumer nodes compared to the first milk producer nodes.

If the inter-dairy trade is neglected, a worst-case situation could be caused on average by 18.4 (minimum 15, maximum 20) contaminated milk producer nodes (Figure 13b). The contingency plan contained a total of 76 (25.8%) different milk producer nodes (Figure 13b). The milk producer nodes with the highest rank in the contigency plan could infect more than 68% of all consumer nodes (Figure 13). The milk producer nodes on the second rank led to a maximal further increase of the damage situation of 12.2% (Figure 13a). In contrast to the results for scenario with inter-dairy trade, we always found the same milk producer node (ID: 100) on the first rank in all simulations in the scenario without inter-dairy trade (Figure 13b). Moreover, three milk producer nodes were found in all 50 performed simulations, but on the ranks 2-5. All other 72 milk producer nodes were identified ten times on average in the simulations on the ranks 2-20.

A “direct neighborhood" ranking of milk producer nodes in the contigency plan without inter-dairy trade was identified for 63 (82.9%) nodes in all simulations (Figure 13b).

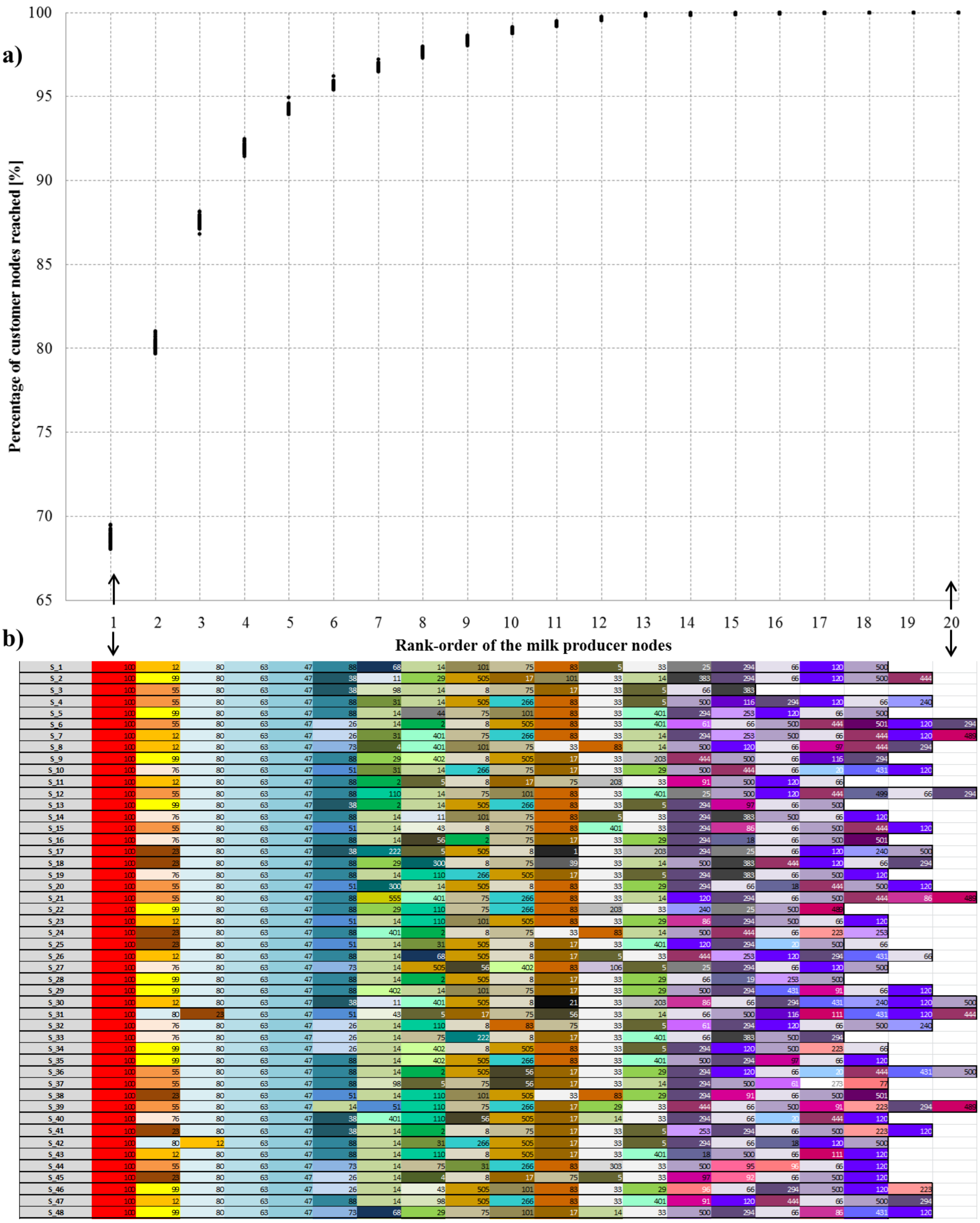


Figure 13. The contingency plan without inter-dairy trade in association with the hypothetically contaminated consumer nodes. a) Size of the damage situation with respect to the number of hypothetically contaminated consumer nodes per rank-order of milk producer nodes. Each point represents the damage caused by a milk producer node in the underlying column of 13b). b) Results of 50 simulations. Each line shows the number of milk producer nodes that are involved in the worst-case situation per simulation; each column shows the rank-order of the milk producer nodes for the worst-case situation according to reached number of consumer nodes. The milk producers on the first rank caused the maximum damage situation. The milk producer nodes on the second place caused the largest increase of infected consumer nodes compared to the first milk producer nodes.

The contingency plan without inter-dairy trade contained 29 milk producer nodes that were not included in the plan that took inter-dairy trade into account (Figure 14b). These milk producer nodes were on average 7.7 times included in all simulations and were between ranks 2 and 19 in the rank-order. Conversely, 39 milk producer nodes existed in the contingency plan with inter-dairy trade that were not included in the plan without inter-dairy trade (Figure 14b). These milk producer nodes had ranks between 1 and 9 in the rank-order and appeared on average 3.4 times in the simulations. 64% of these milk producer nodes were involved twice at the maximum in all performed simulations.

In order to determine the importance of the milk producer nodes for a contingency plan, we used the maximum number of participating milk producer nodes (r=20) as obtained from the greedy-algorithm calculation (Figure 13b). In this context, the maximum impact ($I_{max}(p)$) of a milk producer in the contingency plan is 2000, if the milk producer node is identified on the first rank (r_{max}=20) in all 100 simulations. Figure 14a shows the common intersection of the both contingency plans. 47 (29%) of the milk producer nodes were present in both plans and therefore relevant regardless of the milk flow. The maximum impact of a milk producer node in the contingency plan was 1220 and the minimum 14. The average impact of the milk producer nodes was 260. If the impact of the common milk producer nodes in the contingency plan is compared separately for the trade flows with and without inter-dairy trade, it becomes clear that the milk producer nodes that have a high impact in the trade network without inter-dairy trade do not have the same level of importance for the trade flows with inter-dairy trade (Figure 14a). No clear correlation (R^2 = 0.013) existed between these milk producer nodes regarding their impact on a damage situation. In this context, the milk producer nodes in the plan without inter-dairy trade had a 33.5% higher impact on the damage than the nodes in the list with inter-dairy trade.

Figure 14b shows that the milk producer nodes in the contingency plan with inter-dairy trade possess on average half of the impact for a damage situation as the milk producer nodes in the contingency plan without inter-dairy trade.

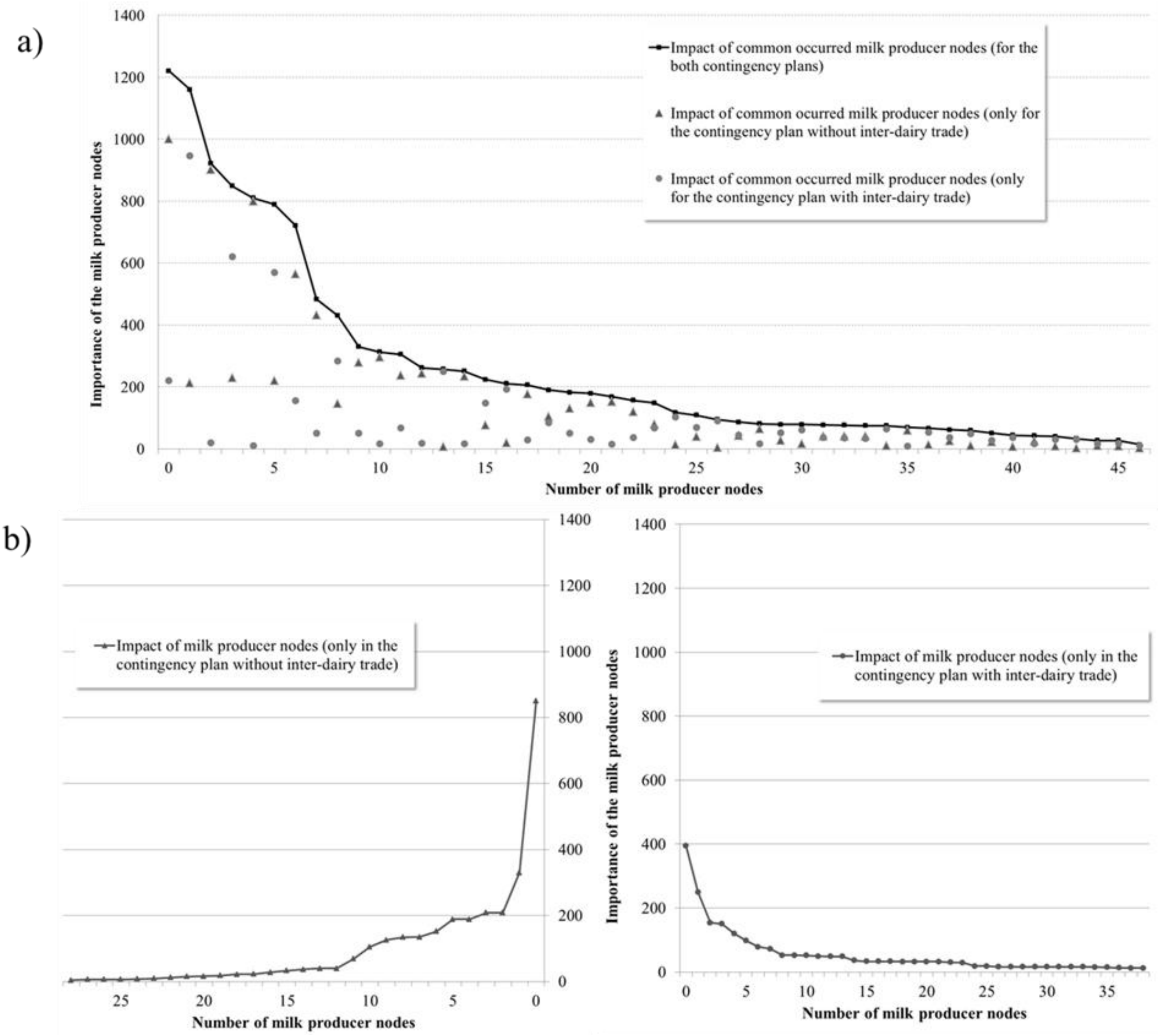


Figure 14. Impact of milk producer nodes, a) present in both contingency plans or b) in only one of the contingency plans

Furthermore, the minimum (n=7 and n=15) number of required milk producer nodes is taken from the greedy calculation as starting point for the genetic algorithm calculations in order to investigate, whether a lower number of milk producer nodes could be found than in the greedy algorithm calculations. For example, the genetic algorithm calculated 5,636*1024 (5 septillion) combination solutions for n=15 and 3,505*1013 (35 trillion) combination solutions for n=7. The genetic algorithm could not find a better solution regarding the minimum number of required milk producer nodes than the greedy algorithm itself.

2.4 DISCUSSION[13]

The description of the milk supply chain in section (i) gives an overview about the existing flows of milk (Figure 6a). In particular the quantification of the number of actors and the milk trade structures can change over the time. As a consequence, nodes identified as important today with respect to the spread of food contamination (see section iii and iv) might be less important tomorrow and vice versa.

To underpin the fact that the description of the milk supply chain in section (i) only provides an overview of trade structures and actors (Figure 6a) further opportunities for differentiation should be mentioned. For example, the direct marketing can be distinguished in different distribution channels, such as the health food store, weekly market, vending machines, free delivery to the door of the customer etc. (Förster, 2011). Likewise the transport of milk can be differentiated into different ways for example by the frequency of the milk collection (e.g. from one day to three day) or the type of transport vehicle (e.g. milk collection trucks with or without trailers, pure vehicle fleet; Weindelmaier and Betz, 2009). Other actors can be included in the milk supply chain, e.g. raw milk testing authorities, the veterinary office etc. In times of crisis, in turn, other actors (e.g. crisis manger, MVG[14] (milk collecting society), authorities, etc.) and other commodity flows (e.g. caused by restriction zones) should be considered into the milk supply chain in order to safeguard the health and the supply of consumers. In conclusion, the conceptual model in section (i) considers on the one hand only the actors and the flow of milk, which exist in times of peace and on the other hand only commercial structures, which are necessary for fulfilling the purpose of the system, namely the supply of the costumers with milk.

The simulation results in section (iii) show that the inter-dairy trade that existed in Germany during the study period influenced the spread of a contaminant and also the risk potential of nodes (Figures 9 and 11). The results clearly show that the inter-dairy trade influences both, the virulence and the vulnerability (Figure 9 and 11; map 2) as well as its variability in comparison to the baseline scenario (Figure 9 and 11; map 1). It is important to notice that even minor inter-dairy trade (1.8%) led to a fourfold increase of the virulence of the milk

[13] In the discussion there are sections, which were taken verbatim from the publications Pinior et al. 2012a,b,c

[14] The MVG (milk collecting society/in German Milchverwertungsgesellschaft) commonly take care of the coordination between producers, dairies and government as well as they coordinate the flow of milk in the event of a crisis (Landesvereinigung Milchwirtschaft, 2009; Anonymous, 2012; LAVES, 2012).

producer nodes and to a threefold increase of the vulnerability of the consumer nodes. Furthermore, seven out of 294 milk producer nodes, which are not involved in the spread of the contagion (resistant) if the inter-dairy trade is 0%, are involved in the spread when a trade between the dairies takes place. The same is true for the 14.5% of all consumer nodes, which were resistant in the damage situation by consideration of the baseline scenario.

However, comparison of our simulation model with the description of the milk supply chain (Figure 4 and 6a) shows that due to missing data on further actors and their respective trade connections in the milk production chain, only a subset of the existing milk supply chain was considered. Therefore, it must be pointed out that conclusions about risk enterprises and critical trade structures in our simulation model have limitations.

The simulation model leads, first, to a noticeable underestimation of the complexity of the trade structure and the geographical range as well as the vulnerability of the consumer nodes. Second, virulence and vulnerability of the nodes has been overestimated.

The reduction of the complexity of the trade structures can also lead to an underestimation of the calculated geographical range and the vulnerability of the consumer nodes. On the one hand, a much more complex trade network (see section (i)) would result from the consideration of all actors (e.g. milk collection companies) and commodity flows (e.g. storage of dairy products) as well as the external trade relations with different dairy products in the dairy industry. Consequently, the structure of every trade network would be altered with the integration of further actors and thus influences the topology of the trade network. For example, the isolated star network-like chain in Figure 7a could be eliminated with the implementation of other trade connections, especially with those who build a bridge to other sub-networks. Chadés et al., (2011) showed that a change in the topology of a network leads to new control management strategies. For example, in cheese production, we must bear in mind that whey used for animal feed will be sent back from the dairy node to the milk producer node and a contamination can be transferred from the dairy node to a milk producer node that was not at risk at the beginning of a contamination. One the other hand, contamination of parts of the feed and food sector is possible via back flows when used in food and fodder production. Moreover, some foodstuffs can be used as ingredients in other food products (Hoorfar, 2011). In this context, other food sectors can be affected by contaminated milk. This was evident in the melamine-scandal in China in 2008. In this case, melamine was contained not only in baby food but also in baking agents, toffees and soy products (Duchowski et al., 2009). Furthermore, not only other food sectors may be affected, other countries could also be supplied with contaminated milk. In this context, the external trade relations in the dairy industry should be included in the model. Due to the high export volume of dairy products (around 44%), inclusion of the external trade connections would lead to a change of the values of the geographical range of the contagion and of vulnerability. In this context, it is assumed that the values of the geographical range of the milk would lead to higher distributions of the contagion and the values of the vulnerability would be minimized as the amount of processed milk would be distributed among different countries. If we consider the external trade connections, the calculated distances (see section (ii)) of distribution between milk producer and milk processing factories (within a distance interval of 0 to 100 km, with a mean of 68 km) would possibly also increase in Germany (Figure 8).

Moreover, we focused on the flow of milk between milk producers, dairies and consumers. As a consequence, the model only considers 61.43% of the processed milk in Germany. According to the study by Pinior et al., (2012b), the remaining processed milk, i.e. about 32% of the total milk production in Germany, is sold from milk collection companies to dairies. Due to the fact, that milk collection companies sell the milk back to the dairy nodes the dairy nodes may feature an even higher in-degree than calculated in section (ii). This means in turn that the vulnerability is underestimated in section (iii). These abovementioned trade connections could not be considered because of missing data.

The overestimation of the vulnerability and virulence of the nodes (see section iii) can be attributed to the following important additional facts:

Firstly, the spread of a contamination is simulated on the assumption that the contamination of a node is passed to another node with p= 1.0, if an edge exists between the nodes. Relevant characteristics of the milk, the kind of biological agents or toxins may have been missed in the model. These features may include e.g. the quantity of the contaminated milk, individual dispositions (Crerar, 2000; Rocourt et al., 2003; McCabe-Sellers and Beattie, 2004; Liu et al., 2010) or internal processes like pasteurization. The above mentioned aspects would minimize the vulnerability of the consumer nodes and virulence of the milk producer nodes. For example, production processes, like pasteurization, could minimize the number of biological agents and toxins, respectively (Bake et al., 2003; Riemelt et al., 2003; VO 853/2004; Zangerl, 2007; Franzen, 2009; Weingart et al., 2010).

A further reason for the overestimation is that possibly existing security measures, like QM – Milk on the producer side or International Food Standard (IFS), British Retail Consortium (BRC), Hazard Analysis and Critical Control Points (HACCP) on the side of processing enterprises were not taken into account. The heterogeneity of security measures and the effectiveness of these measures for the reduction of the spread could thus lead to a more heterogeneous distribution of virulence, resistance and vulnerability as well as the geographical range.

However, the temporal flexibility of trade relations plays a central role in the milk supply chain due to the fluctuation of milk production during the year and in particular by inter-dairy trade in order to compensate the over-and undersupply. In our simulation model, all movements of milk between nodes were summed up for one year. A temporal resolution of trade would have the consequence that the virulence and vulnerability of the nodes would decrease in our model. The number of potential pathways for a contagion could be reduced because a few temporal trade connections would be eliminated in our simulation model. Nicosia et al., (2011) pointed out that aggregated graphs lead to an overestimation of the number of available pathways at each time. Furthermore, if time-resolved trade structures and trade volumes were available, single batch sizes of milk contamination could be considered. This allows the introduction of contaminations in individual batches, whereby more realistic scenarios could be incorporated into our simulation model. Many consumers could be reached by a single batch size. Mid-2012, it became apparent by the imported presumably contaminated strawberries with *norovirus*. In addition, the density of the edges as well as the in- and out-degree of the milk producer nodes and dairy nodes in the milk trade network 2004 and 2010 (see in section ii) would also decrease, if we consider the temporal resolution of trade contacts.

The increased influence of the inter-dairy trade on the spread and the heterogeneous distribution of the values of spread in comparison to the baseline scenario are also obvious in the second model (Figure 12 and 13).

The results show that different trade structures have a significant impact on the number and the rank-order of selected portals of entry for pathogens. If the trade of milk between dairies is taken into account (Figure 12b), more diversity at potential portals of entry per rank-order becomes visible as compared to the list without inter-dairy trade (Figure 13b). This observation can be underpinned by the fact that there were about 50% more potential portals of entry for pathogens on the first 13 ranks compared to the list of portals of entry for the network without inter-dairy trade (Figure 12b and 13b). The consequence of this large number of portals of entry for pathogens per rank is that no general statement can be made, which allows to select milk producer nodes that need to be monitored to mitigate the maximum damage. One consequence of a non-specific selection of the control points would be a delay in coping with the damage situation. In this context, a potential attacker runs a higher risk to select a milk producer node that is not relevant for the spread of the pathogen as the selection is highly dependent on the respective milk trade flow. The situation is different in the contingency plan without inter-dairy trade (Figure 13b), especially for three milk producer nodes (ID: 100; 63; 47). These three milk producer nodes appeared always on the same rank and on the first ranks in all simulations. This means that a potential attacker could reach almost all consumer nodes via these portals of entry.

However, it was shown that about 60% of the milk producer nodes are not suitable as possible portals of entry in the model because only 25.8% (without inter-dairy trade n= 76) and 29.2% (with inter-dairy trade n=86) of the milk producer nodes as portals of entry were identified in a total of 294 possible portals of entry for each contingency plan. This leads to a substantial reduction of the control activities, so that a cost- and time- efficient selection of such milk producer nodes would be possible by decision-makers. With scarce resources, decision-makers can limit their control activities on a small number of milk producer nodes. The limitation of the model results from the fact that the number of milk producer nodes not involved in the spread of a pathogen can be less than 60%, because the greedy algorithm cannot consider the theoretical case that two milk producer nodes cause exactly same extent of damage. 29% of the milk producer nodes were present in both contingency plans and therefore relevant regardless of the milk flow. The limitation is that the common occurring portals of entry (Figure 14a) have a very different impact on the damage situation. It is not possible to tell that milk producer nodes identified as important in one of the contingency plans are also important in the other plan or vice versa. An exception represents the milk producer node with the ID 100. This milk producer presents an important control farm for decision-makers because this milk producer node was found in 66 simulations as the "best" milk producer node for the maximum spread of hypothetical contaminated milk. This milk producer represents a suitable portal of entry regardless of the flow of milk.

Moreover, our model does not consider the microbiology, processing, delivery time-resolved structures and existing security measures etc. that may exist already at different levels of the milk supply chain. All these aspects can influence the number of the consumer nodes reached and the selection of the potential portals of entry for pathogens.

To provide further insights for decision support, the model should be tested with real data from other food supply chains to answer specific question on deliberate or accidental contamination of the producer nodes with pathogens.

2.5 CONCLUSION

In this section, the conclusions of the presented results for safeguarding the milk supply chain are shown. The use of the results for decision support is thematized for both the private and public sectors.

For supporting the decision-makers in the public sector following conclusion can be drawn from the model results:

The decision-makers in the public sector should reconsider the requirements for determining the risk-oriented assessment of food establishments. The assessment of the frequency of official controls of food establishments does not consider the produced and processed amounts or the marketed quantity of the food product of one enterprise in their evaluation of the product risk, which influences the frequency of controls of food operators (see Appendix 1 of the AVV Rüb, 2008). In contrast, e.g. the production volume and the trading volume are essential in the feed sector. Likewise the frequency of animals arriving and the animal trade in the veterinary field build the basis in the risk assessment of the companies (see single integrated multi-annual national control plan by Lower Saxony, 2012). Model results show that the trading volume of the milk, the kind of the structural linkage and the number of trading partners in the milk supply chain are essential for the potential spread of a milk contamination. This should be increasingly considered in the selection and in the frequency of food inspections. The principle should be: actors with a high production and trading volume can cause a great deal of damage and therefore should be controlled more often. This conclusion is combined with some restrictions: First, food and veterinary offices can select food operators with a certain degree of flexibility, which allows considering the production quantity indirectly. One example is the federal state of Thuringia. In their control plan commodity flows are taken into account in the selection of food operators (Thuringia, 2012). Second, goods receipts of food operators are considered as a critical control point in the HACCP and therefore are controlled and monitored. This fact reduces the risk that a large number of trading partners and a high trading volume leads to an increased spread or vulnerability. Third, the conclusion is limited by the overestimation of the simulation results, e.g. because the processing of the dairy products, like pasteurization of the milk, was not considered in the simulation model (see section 2.4).

The designed contingency plan provides a suitable support for decision-makers related to the number and the sequence in which the milk producer nodes should be controlled in order to mitigate the consequences of deliberate contamination by consideration of different commodity flows. This contingency plan shows that, regardless of the actual milk trade flow, some milk producer nodes are more suitable as a portal of entry than others. It was identified that different trade structures have a significant impact on the number and the rank-order of selected portals of entry for pathogens, but it was also shown that 29% of all milk producer nodes are suitable portals of entry regardless of the milk flow. These new insights allow decision-makers to introduce control activities with minimal resources and therefore more efficiently and effectively.

Decision-makers in the private sector can use these models results in order to estimate the effects of a possible contamination and be sensitized to continue optimizing their processes towards food safety and food defense. It was shown that the inter-dairy trade, the choice of trading partners, as well as the structural links between them can have a decisive influence on the spread of contamination in the dairy industry. The private sector should consider these results in their day-to-day business, by making appropriate decisions regarding the number and selection of trade partners in order to prevent large-scale spreads of a contamination.

Especially in time-critical decision-making processes (Schütz et al. 2008), like in crisis situations, the availability and the processing of data on trade relations are essential for a prompt and effective measures in order to curb the crisis. In contrast, it was shown in this work that an increased transparency or a high availability of data about the supply structure can lead to a maximal damage with minimal efforts based on the selection of suitable portals of entry for a potential attacker. Consequently, a balanced compromise between sensitivity of data and data availability must be given. A possible compromise between sensitivity of data and data availability would be the engage and exchange model according to Ellebrecht, 2008; Kasper et al., 2008; Pinior, 2010; Slütter et al., 2010; Breuer, 2011. The model is chiefly based on a two-step-approach: The first step contains that information remain at the companies in peace time. In crisis time, the proceedings for exchanging certain information between public and private authorities will be initiated. This serves to supply the decision-makers with data or information, in order to make targeted decisions for managing a crisis quickly.

In summary the following conclusions for the private sector, especially for the dairies can be drawn:

Firstly, the contingency plan contains important information for the dairies about the vulnerability of their suppliers. These results should be considered by the private sector within their self-monitoring-system. Secondly, the trade between the dairies leads to an increase of the spread of the contamination in comparison to the baseline scenario. Thirdly, the trade between the dairies causes a higher heterogeneity of portals of entry in the contingency plan, which increases the probability of an attacker to select a less suitable milk producer node as portal of entry for an attack. Fourthly, the results show that the protection of supplier data is essential in order to avoid a specific selection of suitable portals of entry by an attacker. Fifthly, data should be always complete, available and processed, so that they can be used for decision support and therefore contribute to an effective crisis management.

2.6 OUTLOOK

Based on the results of this work, other research issues could be treated, especially when better data quality and quantity than in the present work is available.

First of all, the description of the milk chain could be complemented by cross-border trade between Germany and other countries, especially for the surrounding countries Austria, Denmark, France, Italy, Netherlands and Belgium. In particular, the organization of the milk-system in these countries, e.g. according to the number and kind of actors and commercial structures in the milk supply chain could be investigated and compared with the German milk system. In further research investigations special attention could be paid to the recalls of the dairy products described in section (i) with regard to the amounts, the type of products, the frequency and whether these products are reintegrated into the production cycle of a dairy node. This backflow of milk can be used as another possible scenario for entry sources in the simulation model.

Furthermore, with more realistic distribution data on dairy nodes and consumer nodes as well as the trade between dairy nodes, the proposed gravity model could be validated. For the validation of the predicted trade connections, the following information should be available for the year 2010: (a) trade connections and the trade amount of processed milk per trade connection between dairy nodes and consumer nodes as well as between dairy nodes; (b) geographical locations of these dairy nodes and consumer nodes; (c) production capacity of the dairy nodes for processed milk. In this context, it should be noted that the milk is not distributed directly from the dairy to the consumer in the first step (possible exception are fresh dairy products). First the milk gets to storage centers, from where the milk will distributed to retailers (see section (i)). If information about the commodity flow of dairy products between dairy and distributor and between distributor and retailers is available, an aggregation of these commodity flows should be done, so that e.g. information about the trade connection between dairy and consumer can be generated. Following, a comparison can be carried out with the model presented here. The validation of the model with real data would allow conclusions to be made about the magnitude of error in our simulation model. Nevertheless, with these additional data, e.g. where the finished products are stored and sold or with other data, e.g. backflow of dairy products, other certain measures by the network theory like betweenness centrality, closeness etc. can be calculated. New and further insight into the milk supply chain can be gained, which can contribute to safeguard the milk supply chain.

An extension or a change of variables of the gravity model would be possible. Pinior et al., (2011) give an overview of factors that can be important for the selection of trade partners in the milk supply chain (Figure 6b, based on the appendix Pinior et al., 2011). These factors could be supplemented as additional variables in the gravity model in order to predict trade connections. This would require that the influence of these factors on the trade relations must be quantified. Afterwards, a comparison of the generated trade connections by other economic factors with the model variables, which were used here, can be carried out.

Moreover, further models for other years can be generated with the same approach as in this study, by using the same kind of data from the databases of the BLE. These models could be compared in terms of centrality measures, simulation of the spread etc., which raises the possibility to identify changes over time. Here it should be mentioned that this project can be only carried out with older data since an amendment of the law of market regulations goods reporting ordinance (Marktordnungswaren-Meldeverordnung) was adopted on 01.01.2012. This has consequences especially for the analysis of the inter-dairy trade, since only data about purchases of raw milk and raw cream are collected and not such as in 2010 also the purchases of e.g. processed milk[15].

In addition, other aspects which might be introduced into the simulation model are for example the microbiology, processing, delivery time-resolved structures and existing security measures in the companies. The latter should be particularly taken into account, if a contingency plan is created, because trade itself is not an indication of a risk categorization of companies (see regulation AVV Rüb, 2008 and VO 882/2004). Finally, other entry sources as the milk producers themselves can be used in the model. For example, if we use dairies as a target of entry sources, which seem to be suitable, because they collect a lot of milk in a single location, lots of milk could be contaminated. On the other side it must be considered that the dairies have security measures, so that a direct entry of contaminants appears unlikely.

[15] More information about changes of the law of market regulations goods reporting ordinance (Marktordnungswaren-Meldeverordnung) are available at the Federal Office for Agricultural and Food.

Likewise, a modified alert-approach according to Sahneh and Scoglio (2011) could be applied for the model presented here. The authors used an alert approach in order to study how the consumers' reactions affect the spread of the disease. Similar investigations can be applied for the milk supply chain. For instance, how can the consumer's reactions affect the vulnerability, e.g. by a lower consumption of the product concerned. Furthermore, it could be examined, how the spread of a hypothetical milk contamination would change in dependency of the point of time the contamination is discovered. Interventions (e.g. product recalls, introduction of enhance food inspections) at different times initiated by the private and public sector could influence the spread of a contamination. For the latter, however, time-resolved data and information about batch quantities are needed for the modeling.

Another research question could be: how should the flow of milk be organized in a crisis so that the optimal supply of consumers can be guaranteed? In order to answer this question, experts should be consulted, such as the MVG [16] (milk collecting society/in German Milchverwertungsgesellschaft). The MVG includes representatives of the private sector and region's dairy industry associations, which commonly take care of the coordination between producers, dairies and government as well as they coordinate the flow of milk in the event of a crisis (Landesvereinigung Milchwirtschaft, 2009; Anonymous, 2012; LAVES, 2012).

[16] This milk collecting society exists for North Rhine-Westphalia, Lower Saxony and Schleswig-Holstein. This information was collected through personal interviews and the abovementioned sources. No official or unofficial sources could be found for the existence of milk collecting societies in other federal states.

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GENERAL DISCUSSION

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3. GENERAL DISCUSSION

In chapter 2, objectives, methods and results were discussed. At this point of the thesis general aspects picked out with regard to the development of a model and the availability of data in the dairy industry will be discussed in more detail.

THE AVAILABILITY OF DATA AND MODEL DEVELOPMENT

The model results can lead to new or additional knowledge for decision-makers, when models are supported through "accurate and complete" data. Models can also be developed, if data is missing. Due to a high standard of knowledge about the system and using scientific methods, the gaps of data for modeling can be closed. This has been presented in this work through the use of the gravity model. However, by working with real data, it is more likely to achieve the requirements according to Bossel (1987) that a model should be mapped as realistic as possible on the real system. At this point of the work I would like to mention some existing databases in the dairy sector, which collect data for at least one federal state with respect to the dairy industry structures in Germany. These databases could possibly be used for future research: Federal Office for Agriculture and Food (BLE); regions dairy industry association (LV); Federal Office of Consumer Protection and Food Safety (BVL); Agricultural Market Information Company (AMI); Rapid Alert System for Food and Feed (RASFF); Herkunftssicherungs- und Informationssystem für Tiere (HI-Tier). Figure 15 gives an overview about the data, which exists in the above mentioned databases in the dairy industry.

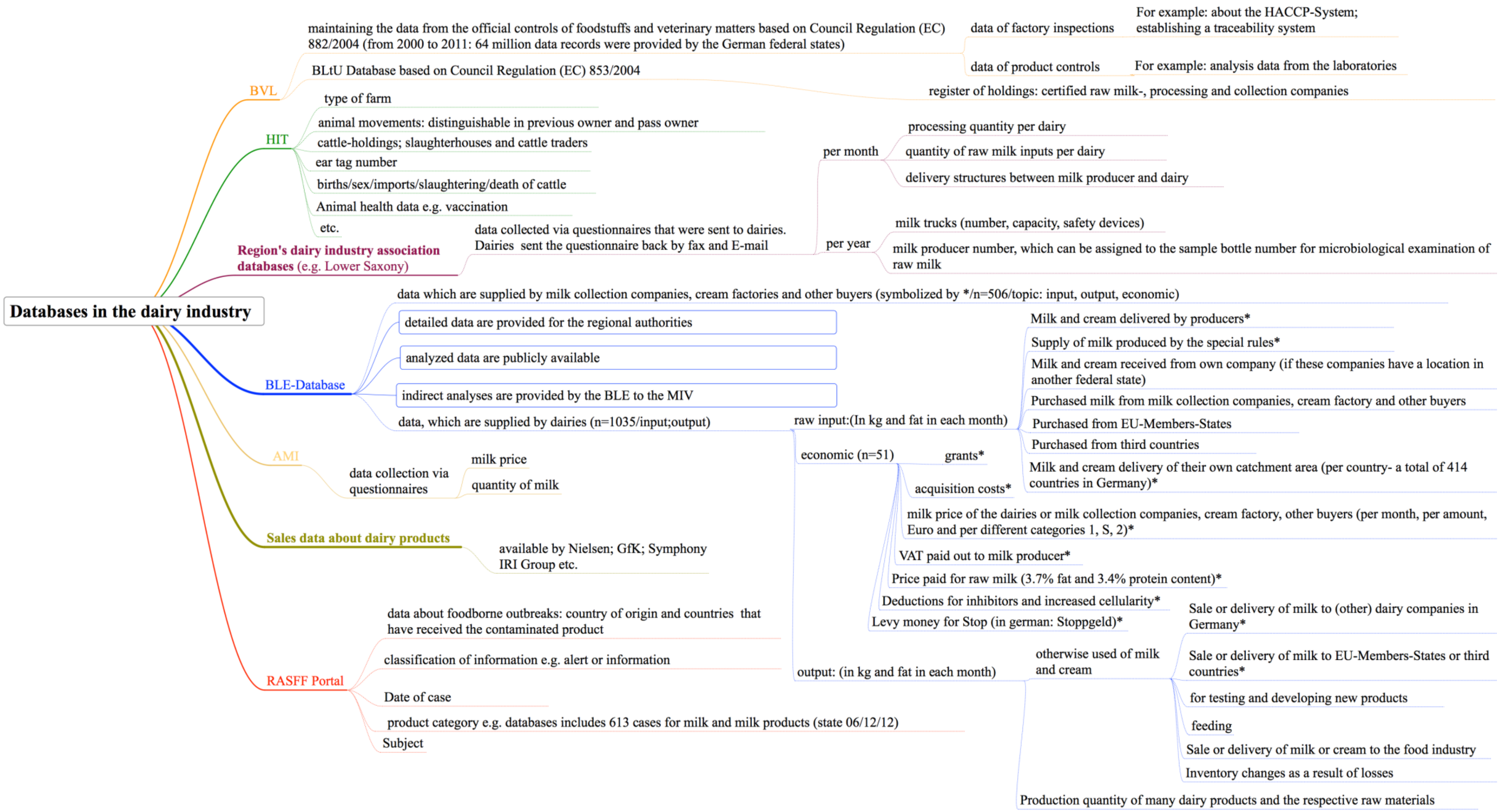

Figure 15. Overview about the databases in the dairy industry

(BVL: Federal Office of Consumer Protection and Food Safety; HIT: Herkunftssicherungs- und Informationssystem für Tiere; BLE: Federal Office for Agriculture and Food; AMI: Agricultural Market Information Company; RASFF: Rapid Alert System for Food and Feed; GfK: Society for Consumer Research; MIV: Milchindustrie Verband; n represents the number of datasets, which are contained in the databases; Source: author’s own illustration; based on the information of here mentioned institutes, individual statements and provided datasets)

Data alone make a minor contribution in order to solve a problem when the data are not interpreted correctly. The actual access to the information can only be obtained by the interpretation of the data (Möws, 2008). A modeling error, i.e. the interpretation error could be minimized or prevented by having recourse to experts, which collect the data and have knowledge about the system, so that a proper allocation and interpretation of the data for the considered system can be done. This is important because data often conceal further information, which would not be obvious by only analyzing the data. This fact can be underpinned by some examples from the milk supply chain. The BLE database includes data about the dairy industry especially data about the dairies, but e.g. it is not clear whether the term dairy describes a whole company (with more than one factory) or a single factory (per location). Consequently, either detailed data per dairy or highly aggregated data were available. Since 2012 this problem has been solved by an amendment of the law of market regulations goods reporting ordinance (in German Marktordnungswaren-Meldeverordnung), where now data about each single factory (per location) are collected (Anonymous, 2012). Other examples for concealed information in the dairy industry are physical and virtual flows of milk. For instance, a physical flow of milk exists, if the dairy obtains the milk directly from milk producer. In contrast, there is a virtual flow of milk, when the milk collection companies reports that the milk has gone through their collection center (because they settle accounts with the milk producers independently) although the physical milk goes directly from farmers to the dairy (Anonymous, 2012). Thereupon the data should be distinguished in virtual and physical flow of milk, if one investigates the flow of goods in the dairy industry. This information by experts makes it possible to better understand the data and allows improving the understanding how the system works.

An interdisciplinary and stable cooperation between the experts, the modeler and the decision-makers of the considered system is necessary for the development of a model. Such cooperation requires mutual trust (Keeling, 2005). This cooperation between the actors should also demonstrate a willingness to share data or provide data, which allow the models to be more the realistic. After Frentrup and Theuvsen (2006) the trust between the actors is one essential precondition for a voluntary data and information exchange in the food sector. In particular, in order to exchange or to obtain data it is necessary to reach an agreement between the cooperation actors with regard to the purpose and the sensitivity of data. Both, "data and knowledge about the data" as well as "the knowledge about the system" can increase the understanding in the modeling about the behavior of the system. Consequently, the support of decision-makers by using of the models will be better. In this manner we can provide decision-makers with prescriptive information derived from the descriptive, comparative and predictive information, which can be used to minimize or avoid negative social, economic and political consequences.

A creation of data cemeteries by gathering and archiving inaccessible data does not lead to a reasonable solution for none of the actors in the agricultural-and food sector. If we are not willing to change our attitude, the data cemeteries will furthermore lead to a slowdown in the progress of research and thus also lead to a slowdown of decision-making.

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SUMMARY

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4. ZUSAMMENFASSUNG

Um Entscheidungsträger mit neuen Erkenntnissen über das Ausmaß bzw. die Effektivität von Strategien zur Verhinderung von Schadenslagen in der Agrar- und Ernährungswirtschaft zu versorgen, werden häufig Simulationsmodelle eingesetzt. Sie finden insbesondere dann Anwendung, wenn sich die Bereitstellung neuer Informationen in der Praxis als zu teuer oder sich Untersuchungen zur Bereitstellung dieser Informationen als nicht durchführbar erweisen. Unter Rückgriff auf Studien zur Entscheidungsunterstützung wurden vier Informationsarten als wesentliche Bestandteile im Entscheidungsfindungsprozess herausgearbeitet: beschreibende, vergleichende, vorhersagbare und handlungsanweisende Informationen. Die Ergebnisse der vorliegenden Arbeit stellen alle vier Informationsarten für Entscheidungsträger in der Milchwirtschaft bereit.

Ziel dieser Arbeit war es, ein Simulationsmodell zu entwickeln, mit dessen Hilfe ausbreitungsfördernde Akteure und Warenströme in der Milchwirtschaft im Falle einer hypothetischen Kontamination identifiziert werden können. Basierend auf den Modellergebnissen wurden Strategien zur Sicherung der Milchversorgungkette für Entscheidungsträger sowohl im öffentlichen als auch im privaten Sektor abgeleitet. Zur Realisierung dieses Ziels war es zuvor notwendig, die Akteure, die strukturellen Verknüpfungen zwischen diesen Akteuren sowie die damit verbundenen Warenströme zwischen den Akteuren in der Milchversorgungskette zu beschreiben und zu quantifizieren. Diese beschreibenden Informationen nehmen insbesondere in der Modellentwicklung eine zentrale Rolle ein, um Erkenntnisse über die operative Funktionsweise des zu modellierenden Systems zu erhalten. Der wesentliche Vorteil dieser beschreibenden Informationen (auch konzeptionelles Modell genannt) ist, dass einerseits ein allgemeines Verständnis über das System „Milchversorgung" vermittelt wird und andererseits, dass das betrachtete System modifiziert, erweitert und an andere Fragestellung angepasst werden kann. Ergänzend zu den beschreibenden Informationen wurden vergleichende Informationen, durch die Analyse zweier Datensätze mittels der Netzwerktheorie, bereitgestellt. Hierbei wurde die Anzahl an Handelskontakten, das jeweilige Handelsvolumen und die Entfernung zwischen den Handelspartnern analysiert sowie Veränderungen im Zeitablauf untersucht. Die Untersuchung wurde sowohl für vertikale als auch für horizontale Warenströme in der Milchwirtschaft durchgeführt. Die beschreibenden und vergleichenden Informationen haben es ermöglicht, erste Hinweise auf relevante Akteure und Warenströme zur Versorgung der Verbraucher mit Milch zu erhalten und diese in das Simulationsmodell zu integrieren und näher zu analysieren. Auf diese Weise konnte der Handel zwischen den Molkereien als entscheidende Handelsstruktur in Bezug auf das Handelsvolumen und Anzahl an vorhandenen Handelskontakten identifiziert werden. Um den Einfluss des Handels zwischen den Molkereien auf die Ausbreitung einer potenziellen Kontamination zu ermitteln, wurde ein Computersimulationsmodell entwickelt, mit dessen Hilfe folgende Fragen beantwortet werden sollten: „Wie groß wäre die potenzielle räumliche Ausbreitung einer Kontamination in der Milchwirtschaft, unter Berücksichtigung des Handels zwischen den Molkereien (horizontale Warenströme), verglichen mit der Vernachlässigung dieser Handelsströme (vertikale Warenströme)? Existieren in diesem Zusammenhang ausbreitungsfördernde Akteure und Warenströme für eine potenzielle Kontamination bzw. gibt es Akteure, die gegenüber einer Kontamination resistent sind? Welche geografische Entfernung würde die kontaminierte Milch zurücklegen?“. Diese Fragen wurden durch die Berechnung der Virulenz, Vulnerabilität und Resistenz der Akteure sowie der geografischen Reichweite einer Kontamination in der Milchwirtschaft, für das Szenario einer potentiellen Eintragung von Agenzien in die Milchversorgungskette, beantwortet. Die Modellergebnisse zeigen, dass das “Risiko“ für die Verbraucher im Mittel bis zu dreimal höher sein kann mit der potenziell kontaminierten Milch beliefert zu werden bzw. die Ausbreitung durch den Milcherzeuger kann in Mittel bis zur viermal höher sein, als unter Vernachlässigung des Handels zwischen den Molkereien. Die Resistenz der Akteure gegenüber einer Milchkontamination ging unter Berücksichtigung horizontaler Warenströme verloren. Ergänzend zu den Schwächen und Stärken des Modells wurde aufgezeigt, wie unter der Anwendung des Wissens über die Funktionsweise des betrachteten Systems und wissenschaftlicher Methoden fehlende Daten über Handelsverknüpfungen zwischen den Akteuren generiert werden können. Aufbauend auf diesem Simulationsmodell wurden handlungsanweisende Informationen für Entscheidungsträger bereitgestellt. Diese Informationen beziehen sich auf die Fragen: „Was sollen die Entscheidungsträger im Schadensfall tun? Welche Akteure, wie viele Akteure und in welcher Reihenfolge müssten die Akteure überwacht werden, um mit möglichst knappen Ressourcen eine Schadenslage zu minimieren?“ Die betrachtete Schadenslage bezieht sich zum einen auf den bewussten Eintrag einer Kontamination auf Primärerzeugerebene und zum anderen auf das Szenario, dass ein potenzieller Angreifer die Strategie verfolgt, mit möglichst wenigen Eintragsquellen eine maximale räumliche Ausbreitung zu erreichen. Unter Anwendung eines Optimierungsalgorithmus konnte festgestellt werden, dass ca. 60% der Primärerzeuger im Modell als potenzielle Eintragsquellen ungeeignet sind und daher beim Vorliegen knapper finanzieller und zeitlicher Ressourcen nicht im Fokus von Überwachungsmaßnahmen liegen müssen. Zusammenfassend ist festzuhalten, dass horizontale Warenströme zu einer weitaus größeren Heterogenität an potenziellen Eintragsquellen führen als vertikale. Dies führt dazu, dass die Umsetzbarkeit der hier angenommenen Strategie des Angreifers erschwert wird.

Die Modellergebnisse dieser Untersuchung verdeutlichen ebenfalls, dass ein verantwortungsbewusster Umgang mit Daten über Versorgungs- und damit Handelsstrukturen notwendig ist, um potenzielle Angriffsflächen im Agrar- und Ernährungssektor auf ein Minimum zu reduzieren.

Vor dem Hintergrund der hier dargestellten Modellergebnisse und dem identifizierten Einfluss des Handels auf die Reichweite einer potenzielle Schadenslage, wurden folgende entscheidungsunterstützenden Schlussfolgerungen für Entscheidungsträger im öffentlichen Sektor abgeleitet:

Produktionsmenge, Anzahl an Handelspartnern, Art der Handelsverknüpfungen und die Reichweite der Handelsaktivitäten von Lebensmittelbetrieben sollten stärker bei der Ermittlung der risikoorientierten Häufigkeit amtlicher Kontrollen berücksichtigt werden. Die Bereitstellung des erstellten Krisenplans zeigt Entscheidungsträgern, dass Überwachungstätigkeiten für ausgewählte Szenarien um die Hälfte reduziert werden können, wenn aktuelle Daten zu Handelsströmen vorliegen.

Für die Privatwirtschaft wurde mittels dieser Arbeit aufgezeigt, dass die Art und Anzahl der Handelspartner einen entscheidenden Einfluss auf die Reichweite einer Schadenslage haben kann. Des Weiteren wurde mit Hilfe des Krisenplans dargestellt, welche Zulieferbetriebe stärker im eigenbetrieblichen Kontrollsystem der Molkereien Berücksichtigung finden sollten. Zudem verdeutlichen die Modellergebnisse, wie wichtig der Schutz von Zulieferungs- und Vertriebsdaten ist, um die Schadensreichweite einer bewussten Eintragung zu minimieren.

Die Einschränkungen zu den hier aufgeführten Schlussfolgerungen für Entscheidungsträger im öffentlichen und privaten Sektor wurden in dieser Arbeit ebenfalls diskutiert. Weiterhin wurde die Notwendigkeit einer besseren Datenqualität und Datenquantität für die Bereitstellung weiterer entscheidungsunterstützender Informationen thematisiert.

4. SUMMARY

In order to provide decision-makers with new insights about the extent and the effectiveness of strategies to prevent incidents in the agri-food industry, simulation models are commonly used. They are particularly applied when the provision of new information in practice is too expensive or investigations for providing this information prove to be not feasible. Relying on studies about decision support four types of information were identified as essential components in the decision-making process: descriptive, comparative, predictive and prescriptive information. The results of this thesis provide all four types of information for decision-makers in the dairy industry.

The aim of this study was to develop a simulation model that allows to identify spread promoting actors and flows of goods in the dairy industry in the case of a hypothetical contamination. Based on the model results, strategies for decision-makers in both the public and private sectors for safeguarding the milk supply chain have been derived. To realize this objective, it was previously necessary to describe and to quantify the actors, the structural links between these actors and the associated flow of goods between the actors in the milk supply chain. These descriptive information take a central role, particularly in model development, in order to obtain insights into the functioning of the operating system to be modeled. The main advantage of these descriptive information (also called conceptual model) is that on the one hand a general understanding of the system "milk supply" is imparted and on the other hand, that the considered system can be modified, extended and adapted to different question. In addition to the descriptive information comparative information was provided by the analysis of two data sets using the network theory. Here, the number of trade contacts, the respective trading volume and the distance between the trading partners were analyzed and changes over time were investigated. The study was carried out for both vertical as well as horizontal flow of goods in the dairy industry.

The descriptive and comparative information made it possible to obtain a first indication of relevant actors and flows of goods for supplying the consumers with milk, to integrate them into the simulation model and analyze them in more detail. In this way, the trade

between the dairies could be identified as a crucial trade structure in terms of trading volume and number of existing trade contacts.

In order to determine the impact of trade between the dairies on the spread of a potential contamination, a computer simulation model was developed by means of which the following questions should be answered: “What would be the potential spatial spread of a contamination in the dairy industry, taking into account trade between dairies (horizontal flow of goods), compared to the neglect of these trade flows (vertical flow of goods)? In this context, are there spread promoting actors and flows of goods respectively are there actors that are resistant to contamination? Which geographical distance would be travelled by the contaminated milk?“. These questions were answered by calculating the virulence, vulnerability and resistance of the actors as well as the geographical range of a contamination in the dairy industry, for the scenario of a potential entry of agents in the milk supply chain. The model results show that the "risk" for the consumer can on average be up to three times higher to be supplied with the potentially contaminated milk and the spread through the milk producers can be up to four times higher than neglecting the trade between the dairies. The resistance of the actors against contamination of milk was lost, taking into account the horizontal flow of goods.

In addition to the strengths and weaknesses of the model it was shown how missing data on trade links between the actors can be generated, by applying scientific methods and the knowledge about the functioning of the system considered.

Based on this simulation model prescriptive information for decision-makers were provided. These information relate to the questions: "What should decision-makers do in case of damage? Which actors, how many actors and in what order should the actors be monitored in order to minimize a damage situation with scarce resources?" The observed damage situation relates firstly to the deliberate entry of a contamination at primary producer level and secondly on the scenario that a potential attacker pursues the strategy to achieve a maximum spatial distribution with a minimum of portals of entry.

By using an optimization algorithm could be found that about 60% of primary producers in the model are unsuitable as potential portals of entry and therefore must not be the focus of monitoring measures in presence of limited financial and time resources. In summary, it can be stated that horizontal flow of goods leads to a much greater heterogeneity of potential portals of entry than vertical. This complicates the feasibility of the attacker's strategy. The model results of this study also demonstrate that a responsible use of data on supply and trading structures is necessary in order to reduce the potential attack targets in the agri-food sector to a minimum.

Against the background of the model results presented here and the identified impact of trade on the scope of a potential damage situation, following decision support conclusions for decision-makers in the public sector have been derived:

Production volume, number of trading partners, kind of trade links and the range of the trading activities of food establishments should be given greater consideration in the calculation of risk-based frequency of official controls. The provision of the prepared contingency plan shows decision-makers that surveillance activities for selected scenarios can be reduced by half if current data on trade flows are present.

It has been shown by this study that for the private sector the type and number of trading partners can have a significant impact on the range of a damage situation. Furthermore, it was shown by means of the contingency plan, which suppliers should find more consideration in the operational-control-system of the dairies. In addition, the model results illustrate the importance protecting supply and distribution data in order to minimize the size of damage caused by deliberate entry of a contamination.

The limitations to the conclusions listed here for decision-makers in the public and private sectors have been discussed in this work. Furthermore, the need for better data quality and quantity in order to provide further decision-supporting information has been an issue.

APPENDIX

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The German milky way: trade structure of the milk industry and possible consequences of a food crisis

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ABSTRACT

The aim of this paper is to analyze the structure of the trade network between milk producers, dairies and milk collection companies in Germany by network analysis using suitable centrality measures. The study shows that structures exist among the relevant enterprises which are critical for the spread of a contamination in the German milk trade network. The results may be used to improve food security.

(**Key words:** Trade connections, milk supply chain, Network analysis, spread of contagion, gravity model)

The trade network in the dairy industry and its implication for the spread of contamination

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ABSTRACT

In case of an outbreak of a foodborne disease, administrative decisions in the context of crisis management are only efficient, if they follow standard practices and are at the same time specifically adapted to the outbreak situation in a timely manner. These goals are hard to achieve. The complexity of national and global trade structures obscure a clear view of trade flows and, as a consequence, it is often impossible to unravel complex trade links timely. Furthermore, increasing public concerns about possible health hazards caused by global trade put further pressure on decision makers.

The aim of this paper is to unveil the specific trade structures of the German milk supply chain, to highlight how these structures could affect the spatial spread of a hypothetical contaminant and to quantify the risk that the contaminant reaches the consumer. To achieve this goal, the vertical and horizontal trade links between milk producers, dairies and consumers are taken into account. The horizontal flow of milk between dairies (inter-dairy trade), which is intended to compensate a temporary over-or undersupply of milk, is of special importance in this respect. We hypothesize that the extent of inter-dairy trade significantly influences the spatial spread of contaminated milk and the contamination risk. This hypothesis is tested using a computer simulation model that predicts the hypothetical spread of a contaminant via trade of milk. The model parameters were estimated using trade data collected in the years 2004 and 2010.

The results of our study indicate that inter-dairy trade significantly influences the contamination risk. Compared to a scenario with no inter-dairy trade, the risk that contaminated milk can reach the consumer is up to four times higher even with moderate inter-dairy trade. The contamination risk depends on the extent of the inter-dairy trade in a non-linear way and reaches its maximum asymptotically when inter-dairy trade increases. The contamination risk exhibits considerable spatial variation, which can be utilized to implement more accurate food control interventions in times of a crisis caused by a foodborne disease.

(**Key words:** gravity model of trade, network analysis of flow of goods, food safety)

Decision support for risks managers in the case of deliberate food contamination: The Milk Supply Chain as an example

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(under review)

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 pathogen into the supply chain of milk was simulated in a scenario where milk producers serve as the portal of entry and consumers of milk represent the target to be affected by the pathogen. It is shown that the portal of entry has 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 portals of entry 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 pathogen 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 portals of entry.

The results indicate that, regardless of the actual milk trade flow, some milk producers are more suitable as a portal of entry than others. The identification of suitable portals of entry may help risk managers to focus on these farms in a contingency plan that improves the sensitivity of control activities related to deliberate contamination.

(**Key words:** milk supply chain, greedy algorithm, contingency plan)

THE DEPOSIT OF THE SOURCE CODE[17]

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[17] Only a part of the program code is presented. The program was written by Mario Konschake.

SOURCES CODE OF THE SIMULATION MODEL

```
def __init__(self, p0):
self.CORR = 3.06 * 1e7    #set to mean_deg(municip)
self.COUNTIES = 294.0
self.DAIRIES = 80
self.MUNICIPS = 12223.0
self.municip_xy = self.__municip_xy()
self.dairy_xy = self.__dairy_xy()
self.county_xy = self.__county_xy()
county_graph = self.__county_graph()
dairy_graph = self.__dairy_graph(p0)
municip_graph = self.__municip_graph()
self.__write_density(p0, dairy_graph)
self.milknet = self.__milknet(county_graph, dairy_graph, municip_graph)
self.ranges = self.__ranges()
def county_vir(self):
vir = [(n, len(r)/self.MUNICIPS) for n,r in self.ranges.iteritems()]
return dict(vir)
def county_distances(self):
d = dict.fromkeys(self.ranges)
for u, ranges in self.ranges.iteritems():
distances = [self.__dist(self.county_xy[u], self.municip_xy[v]) for v in ranges]
d[u] = int(np.nan_to_num(np.median(distances)))
return d
def municip_vul(self):
d = dict.fromkeys(self.municip_xy, 0)
for ranges in self.ranges.itervalues():
for r in ranges:
d[r] += 1
d = [(k, v/self.COUNTIES) for k,v in d.iteritems()]
return dict(d)
```

```
def municip_degree(self):
degrees = self.milknet.degree()
degrees = [d for n,d in degrees.iteritems() if self.__is_municip(n)]
return np.mean(degrees), np.median(degrees), min(degrees), max(degrees)
def dairy_degree(self):
outdegrees = self.milknet.out_degree()
indegrees = self.milknet.in_degree()
degrees = [(n, indegrees[n], outdegrees[n]) for n in outdegrees.iterkeys() if self.__is_dairy(n)]
return degrees
def edgelist(self):
return self.milknet.edges()
def __county_graph(self):
edges = [(u,v) for u,v in np.loadtxt("data/erzeuger_molkerei.txt", dtype=int)]
D = nx.DiGraph()
D.add_edges_from(edges)
return D
def __dairy_graph(self, p0):
sell = self.__dairy_sell()
buy = self.__dairy_buy()
xy = self.dairy_xy
D = nx.DiGraph()
D.add_nodes_from(xy.keys())
for u in D.nodes_iter():
for v in D.nodes_iter():
p = p0 * sell[u] * buy[v] * 1.0/self.__dist(xy[u], xy[v])
if u != v and rnd() <= p:
D.add_edge(u,v)
return D
def __municip_graph(self):
inhab = self.__municip_inhab()
cap = self.__dairy_cap()
d_xy = self.dairy_xy
```

```
m_xy = self.municip_xy
D = nx.DiGraph()
for u in d_xy.iterkeys():
for v in m_xy.iterkeys():
p = self.CORR * cap[u] * inhab[v] * 1.0/self.__dist(d_xy[u], m_xy[v])
if rnd() <= p:
D.add_edge(u,v)
return D
def __milknet(self,county_graph, dairy_graph, municip_graph):
D = nx.DiGraph()
D.add_edges_from(county_graph.edges())
D.add_edges_from(dairy_graph.edges())
D.add_edges_from(municip_graph.edges())
return D
def __write_density(self, p0, dairy_graph):
degrees = dairy_graph.degree().values()
file = open("results/p0_sum_mean_stdv_median_min_max.txt", "a")
file.write(str(p0)+" "+str(sum(degrees))+" "+str(np.mean(degrees))+" "+str(np.std(degrees))+" "+str(np.median(degrees))+" "+str(min(degrees))+" "+str(max(degrees))+"\n")
file.close()
return None
def __ranges(self):
erz = [n for n in self.milknet.nodes() if self.__is_county(n)]
ranges = [(e ,self.__range(e)) for e in erz]
return dict(ranges)
def __range(self, n):
nodes = nx.algorithms.traversal.depth_first_search.dfs_preorder_nodes(self.milknet, source=n)
nodes = [n for n in nodes if self.__is_municip(n)]
return nodes
def __dist(self,xy1, xy2):
dx = xy1[0] - xy2[0]
 dy = xy1[1] - xy2[1]
```

```
 d = sqrt(dx*dx + dy*dy)
 d = max(10, d/1000) #in 1km, mind 10km
return d
def __dairy_sell(self):
tpls = [(int(d),v) for d,v in np.loadtxt("data/molk_an_ab.txt", usecols=[0,2])]
return dict(tpls)
def __dairy_buy(self):
tpls = [(int(d),v) for d,v in np.loadtxt("data/molk_an_ab.txt", usecols=[0,1])]
return dict(tpls)
 def __dairy_xy(self):
tpls = [(d,(x,y)) for d,x,y in np.loadtxt("data/molk_xy.txt", dtype=int)]
return dict(tpls)
def __county_xy(self):
tpls = [(c,(x,y)) for c,x,y in np.loadtxt("data/kreis_xy.txt", dtype=int)]
return dict(tpls)
def __municip_xy(self):
tpls = [(m,(x,y)) for m,x,y in np.loadtxt("data/gemeinde_xy.txt", dtype=int)]
return dict(tpls)
def __municip_inhab(self):
tpls = [(int(m), inh) for m, inh in np.loadtxt("data/gemeinde_einwohner.txt")]
return dict(tpls)
def __dairy_cap(self):
tpls = [(int(d), cap) for d, cap in np.loadtxt("data/molk_kap.txt")]
return dict(tpls)
def __is_municip(self, n):
 return 10000 < n <= 160
def __is_dairy(self, n):
return n >= 100000
def __is_county(self, n):
return n <= 10000
```

SUPPLEMENTS

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I would like to dedicate this work to all here mentioned persons.

LIST OF PUBLICATIONS

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Journal publications (peer-reviewed)

Pinior, B.; Platz, U.; Ahrens, U.; Petersen, B.; Conraths, F.; Selhorst, T (2012a): The German Milky Way: trade structure of the milk industry and possible consequences of a food crisis. Journal on Chain and Network Science, Vol.12 (1), pp. 25-39.

Pinior, B.; Konschake, M.; Platz, U.; Thiele, H.; Petersen, B.; Conraths, F.C.; Selhorst, T (2012b): The Trade network in the dairy industry and its implication for the spread of a contagion. In: Journal of Dairy Science, Vol. 95 (11), pp. 6351-6361.

Pinior, B.; Conraths, F.C.; Petersen, B.; Selhorst, T (2012c): Decision support for risks managers in the case of deliberate food contamination: The Milk Supply Chain as an example (Submitted)

Conference papers (peer-reviewed)

Belaya, V.; Hansen, H.; **Pinior, B** (2013): Measuring the costs of foodborne diseases: A review and Classification of the Literature. In: Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e.V., Bd. 48, pp. 47-58.

Wilke, T.; Belaya, V.; **Pinior, B** (2012): How to measure food safety? A review of relevant literature. In: Rickert, U., Schiefer, G (eds.): System Dynamics and Innovation in the Food Network. Proceedings of the 6th International European Forum, pp. 61-83.

Pinior, B.; Belaya, V.; Petersen, B.; Selhorst, T (2011): Structures and relationships in supply chains and networks: conceptual issues and application in German dairy sector. Conference proceedings (CD) at the International Conference on Economics and Management of Networks, pp. 1-21.

Contributions to scientific conferences

Pinior, B.; Konschake, M.; Kolski, P.; Lentz, H.; Slütter, S.; Selhorst, T (2012): Optimierungsalgorithmen in der Milchwirtschaft und ein Paradoxon in der Gefahren-Schadenslagen-Berechnung. Proceedings and Presentation at the Internationale DACH-Epidemiologie Tagung, Deutsche Veterinärmedizinische Gesellschaft, pp. 45-47, ISBN: 978-3-86345-098-4; 5-7 September, Neuruppin, Germany.

Belaya, V.; Hansen, H.; **Pinior, B** (2012): Measuring the costs of foodborne diseases: A review and Classification of the Literature. Presentation at GEWISOLA Herausforderungen des globalen Wandels für Agrarentwicklung und Welternährung, 26-28. September, Hohenheim, Germany.

Lentz, H.; Konschake, M.; Kolski, P.; **Pinior, B.**; Selhorst, T (2012): Epidemische Leitfähigkeit zeitabhängiger Netzwerke. Proceedings and Presentation at the Internationale DACH Epidemiologie Tagung, Deutsche Veterinärmedizinische Gesellschaft, pp. 43, ISBN: 978-3-86345-098-4; 5-7 September, Neuruppin, Germany.

Kolski, P.; **Pinior, B**.; Selhorst, T (2012): Visualisierung und Analyse von Epidemien in Echtzeit. Proceedings and Presentation at the Internationale DACH Epidemiologie Tagung, Deutsche Veterinärmedizinische Gesellschaft, pp. 38, ISBN: 978-3-86345-098-4; 5-7 September, Neuruppin, Germany.

Pinior, B (2012):
The spread of contaminated milk: Identification of high-risk companies and the vulnerability of communities. Presentation at the Food Safety Management Conference, 19-20 June 2012, Campden BRI, United Kingdom (UK).

Pinior, B.; Slütter, S.; Wilke, T.; Selhorst, T.; Petersen, B (2012):
Prozess-Referenzmodell (PRM) nach der ISO/IEC 15504 für das Aufschaltungs- und Austauschmodell (AAM) von krisenrelevanten Informationen. Proceedings and Poster presented at the International DACH Epidemiologie Tagung, Deutsche Veterinärmedizinische Gesellschaft, pp. 108-109, ISBN: 978-3-86345-098-4; 5-7 September, Neuruppin, Germany.

Slütter, S.; Schulze-Geisthövel, S.; **Pinior, B**.; Wilke, T.; Van der Wolf, P.; Petersen, B (2012): Support in Crisis Communication by forming a strategic alliance in information management on the example of the German pork production chain. Proceedings and Poster presented at the Internationale DACH Epidemiologie Tagung, Deutsche Veterinärmedizinische Gesellschaft, pp. 114-115, ISBN: 978-3-86345-098-4; 5-7 September, Neuruppin, Germany.

Pinior, B.; Selhorst, T (2012): Trade structures as spread catalyst of agents? Investigation of trade patterns in the German dairy industry. Poster presented at the International Food Safety Conference, 21-23 February, Dubai, United Arab Emirates.

Slütter, S.; Schulze-Geisthövel, S.; **Pinior, B**.; Wilke, T.; Van der Wolf, P.; Petersen, B (2012): Maßnahmen zur Früherkennung und Bekämpfung der Schweinepest in Deutschland und den Niederlanden im Vergleich. Proceedings and Poster presented at the International DACH Epidemiologie Tagung, Deutsche Veterinärmedizinische Gesellschaft, pp. 116-117, ISBN: 978-3-86345-098-4; 5-7 September, Neuruppin, Germany.

Pinior, B (2012): Investigation of failures in interdependent food systems: effects of structural change in the meat and dairy industry to the fragmentation of a production flow. Poster presented at the International Food Safety Conference, 21- 23 February, Dubai, United Arab Emirates.

Pinior, B (2012): How can high-risk companies be identified and which role takes the trade of food in the spread of food contamination. Proceedings and Poster presented at the 13. Fachsymposium Lebensmittelmikrobiologie 28. - 30. March, pp. 50, Stuttgart, Germany.

Belaya, V.; **Pinior, B** (2012): Economic assessment of food safety improvement in supply chains: clarification of conceptual issues. Proceedings and Presentation at the 10th Wageningen International Conference on Chain and Network Management (WICaNeM 2012), 23-25 May, Wageningen, The Netherlands.

Pinior, B.; Platz, U.; Ahrens, U.; Petersen, B.; Conraths, F.; Selhorst, T (2012): The German Milky Way: Trade structure of the milk industry and possible consequences of a food crisis. Proceedings and Presentation at the 10th Wageningen International Conference on Chain and Network Management (WICaNeM 2012), 23-25 May, Wageningen, The Netherlands.

Pinior, B (2012): Computer simulations of the spread of contamination on trade networks in the dairy industry. Proceedings and Presentation at the 13. Fachsymposium Lebensmittelmikrobiologie 28. - 30. März, pp. 27, Stuttgart, Germany.

Pinior, B (2012): Vernetzte Lebensmittelproduktion: Von Daten zur Risikoabschätzung. Im Rahmen der Graduate School. Meat Challenge, 27. January, Bonn, Germany.

Slütter, S.; Wilke, T.; **Pinior, B**.; Breuer, O.; Petersen, B (2012): Support in crisis communication by forming a strategic alliance in information management on the example of the German pork production chain. Presentation at the Food Safety Management Conference. 19-20 June, Campden BRI, United Kingdom (UK).

Selhorst, T.; **Pinior, B**.; Konschake, M.; Lentz, H.; Kolski, P (2012): Can livestock trade network properties facilitate the development of efficient strategies for animal disease prevention? EE² - Epiwork/Epifor 2nd International Workshop - Facing the Challenge of Infectious Diseases, Pré-Saint-Didier, 18-20 January, Aosta, Italy.

Wilke, T.; Belaya, V.; **Pinior, B** (2012): How to measure food safety? A review of relevant literature. Presentation at the International 6th European Forum on Innovation and System Dynamics in Food Networks. 13-17 February, Innsbruck, Austria.

Pinior, B.; Belaya, V.; Hansen, H.; Selhorst, T (2011): The relevance of supply chain structures and relationships for studying the impact of food scandals in German dairy sector. Proceedings and Presentation at the Milk Society of Milk Science Conference, 12-13 September, Bern, Switzerland.

Pinior, B.; Kasper, M.; Konschake, M.; Kolski, P.; Lentz, H.; Selhorst, T (2011): Realitätskonforme Netzlogistikstrukturen als Ausbreitungskatalysator von Agenzien. Proceedings and Presentation at the Internationale DACH Epidemiologie Tagung, p. 39, ISBN: 9783950204254; 31-02 August-September, Wien, Austria.

Pinior, B.; Belaya, V.; Petersen, B.; Selhorst, T (2011): Structures and relationships in supply chains and networks: conceptual issues and application in German dairy sector. Proceedings (CD) and Presentation at the International Conference on Economics and Management of Networks, 1-3 December, pp. 1-21, Limassol, Cyprus.

Kolski, P.; Lentz, H.; **Pinior, B**.; Konschake, M.; Selhorst, T (2011): Modellierung, Visualisierung von Epidemien. Presentation at the 3. Treffen der Moderatoren der Regionalen Netzwerke. Gemeinsam gegen MRSA/MRE, 15-16 December, Wernigerode, Germany.

Kasper, M.; Konschake, M.; **Pinior, B**.; Kolski, P.; Lentz, H.; Selhorst, T (2011): Handel, ja oder nein? Entwicklung von Entscheidungshilfen im Krisenmanagement. Proceedings and Presentation at the Internationale DACH Epidemiologie Tagung, p. 37- 38, ISBN: 9783950204254; 31-02 August-September, Wien, Austria.

Lentz, H.; Kasper, M.; Konschake, M.; Kolski, P.; **Pinior, B**.; Selhorst, T (2011): Über die Bedeutung der Zeitkomponente in Handelsnetzwerken. Proceedings and Presentation at the Internationale DACH Epidemiologie Tagung, p. 40, ISBN: 9783950204254; 31-02 August-September, Wien, Austria.

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Kasper, M.; Konschake, M.; **Pinior, B**.; Kolski, P.; Lentz, H.; Wilke, T.; Brinkmann, D.; Petersen, B.; Selhorst, T. (2011): In: Stegemann, A., Heres, L., Swanenburg, L. & Peter van deer Wolf .(eds.): Proceedings Book - 9th International Conference on the Epidemiology and Control of biological, chemical and physical hazards in pigs and pork, p. 75-78, 19.-22. June, Maastricht, The Netherlands.

Other publications:

Pinior, B (2010): Erstellung eines Referenzmodells für die Reifegradbestimmung von Aufschaltungs- und Austauschkonzepten im Krisenmanagement. Diplomarbeit, Univ. Bonn, 140 p.

CURRICULUM VITAE

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Place of birth: Ratibor (Poland)

Date of birth: 30.07.1986

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WORK EXPERIENCE

03/2013-present	**Assistant Professor:** Biometeorology & Mathematical Epidemiology Group; Institute for Veterinary Public Health, University of Veterinary Medicine Vienna, Austria
01/2011-02/2013	**Scientific Assistant:** Friedrich-Loeffler-Institut; Federal Research Institute for Animal Health, Institute of Epidemiology, Wusterhausen, Germany
10/2010-12/2010	**Research Assistant:** Department of Preventive Health Management; Institute for Animal Sciences, Faculty of Agriculture, University of Bonn, Germany
09/2010-11/2010	**Research Assistant:** Trans Border Integrated Quality Assurance (registered association), Germany
04/2009-02/2010	**Research Assistant:** Department of Market Research, Institute for Food and Resource Economics, Faculty of Agriculture, University of Bonn, Germany

EDUCATION AND ADVANCED EDUCATION

04/2013-06/2013	**Coursera program:** Statistics Sciences, University of Toronto
04/2013-06/2013	**Coursera program:** Principles of Microeconomics, University of Pennsylvania
2012	**Certification in:** Microbial Risk Assessment and Mitigation Workshop towards a Quantitative HACCP Approach; IAFP's First Middle East Symposium on Food Safety; Dubai, United Arab Emirates
2011-present	**Acquisition of certificate:** International competencies, University of Bonn, Germany
01/2011-01/2013	**PhD Student:** Institute of Animal Science, Preventive Health Management Group, Faculty of Agriculture University of Bonn, Germany
10/2008-12/2010	**Additional qualifications:** DGQ Quality Systems Manager- Junior; University of Bonn, Germany
2008- 2010	Visit of the Wall Street Institute, Köln/ Bonn, Germany
10/2006-12/2010	**Studies in Nutrition and Household Science**: Academic title: Dipl. Oec. Troph., (grade:1,3; grade for diploma thesis: 1,0), Faculty of Agriculture, University of Bonn, Germany

PROJECT WORK/STUDIES/ ORGANIZATION OF SCIENTIFIC EVENTS

01/2011-02/2013	SiLeBAT Project (Securing the Feed and Food Supply Chain in the Event of Biological- and Agroterrorism (BAT) Incidents)
2012	Organization of the International Conference DACH-Epidemiology
2012	Organization of the Workshop IRIS (Session: Data protection and data management)
02/2010-12/2010	Safeguard Project INTERREG IV (Sound Animals and healthy Food within the Euregio Guaranteed by an United Approach [between Dutch and German / public and private entities]
05/2010	Scientific excursion and economic work camp, University of Florida, United States of America
2008-2010	Support of various research studies: consumer perception of Fair Trade products, mince, and cereals.

AWARDS

2011	**Winner of the young scientist's award 1st place (2011):** Topic: "Realitätskonforme Netzlogistikstrukturen als Ausbreitungskatalysator von Agenzien (in German): The International Conference DACH- Epidemiology, 31.08- 02.09.2011, Vienna, Austria; Awarded by the German-, Swiss-, and Austrian Association for Veterinary Medicine

2012 **Best Poster award 2nd place (2012):**

Topic: "Investigation of failures in interdependent food systems: effects of structural change in the dairy and meat industry to the fragmentation of a production flow". The Seventh Dubai International Food Safety Conference and IAFP's First Middle East Symposium on Food Safety; 21- 23.02.2012, Dubai, United Arab Emirates

TEACHING

04/2010-07/2010 **Tutor for analysis of special Food Markets:** Department of Market Research; Institute for Food and Resource Economics, Faculty of Agriculture, University of Bonn, Germany

10/2008-02/2009 **Tutor for analysis of Food Markets:** Department of Market Research, Institute for Food and Resource Economics, Faculty of Agriculture, University of Bonn, Germany