RESEARCH

Verena Brenner

Causes of Supply Chain Disruptions

An Empirical Analysis in Cold Chains for Food and Pharmaceuticals

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Dissertation Jacobs University Bremen, 2014, Germany

ISBN 978-3-658-08661-9 ISBN 978-3-658-08662-6 (eBook)
DOI 10.1007/978-3-658-08662-6

Library of Congress Control Number: 2015930260

Springer Gabler

Printed on acid-free paper

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(www.springer.com)

Preface

How can wasteful handling of such precious goods as food and pharmaceuticals be reduced between production and consumption?

This was the key question at the beginning of this research project. Having witnessed vivid and frank discussions between logistics experts from all segments of the cold chain in conferences and workshops during my work for the Cool Chain Association (CCA), I became increasingly curious and involved in the search for solutions. To prevent massive losses of nutritious food and life-saving pharmaceuticals caused by supply chain disruptions is one of the main goals of this association and its members. However, I realized that a more systematic and academic way of addressing the problem would be required.

During my search for cooperation partners from the scientific world, Professor Hülsmann offered me a position as PhD student and Research Associate in his workgroup "Systems Management" at Jacobs University Bremen. Hence, I took the opportunity to analyze causes of supply chain disruptions in more depth by linking scientific and industrial perspectives.

In the following years, research projects in logistics and supply chain management as well as scientific seminars and conferences broadened my horizon and deepened my insights into cold chain logistics, but also into scientific research methods and systematic analyses. Furthermore, discussions with my research colleagues, but also my former boss and colleagues from the CCA reinforced my motivation and determination to find out why supply chain disruptions occur.

These efforts led to the absolute highlight of this project, namely the empirical survey among cold chain managers from around the world. Their interest and willingness to support my research was amazing and showed how relevant the topic is for the industry. In the future, the results will hopefully be starting points for further research and will be considered in the design of supply chain partnerships.

These years of research were incredibly tough, challenging and rewarding. To all the people who guided and supported me as well as this project: thank you very much!

Verena Brenner

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List of Abbreviations

AHP	Analytic Hierarchy Process
A/N	Author's Note
AVE	Average Variance Extracted
BOL	Bill of Lading
BRC	British Retail Consortium
CAPA	Corrective and Preventive Action
CBL	Dutch Food Retail Association
CCQI	Cool Chain Quality Indicator
CFSAN	Center for Food Safety and Applied Nutrition
CM	Category Management
DC	Distribution Centre
EC	European Commission
ECR	Efficient Consumer Response
EDI	Electronic Data Interchange
EU	European Union
ECSLA	European Cold Storage and Logistics Association
FAO	Food and Agriculture Organization of the United Nations
FEFO	First-Expired-First-Out
FoB	Free-on-Board
FPEF	Fresh Produce Exporter's Forum
GoF	Goodness of Fit
HACCP	Hazard Analysis and Critical Control Points
IATA	International Air Transport Association
Incoterms	International Commercial Terms
IFS	International Food Standard
JIT	Just in Time
KPI	Key Performance Indicator
LOSA	Line Operations Safety Audits
LSP	Logistics Service Provider
MCAR	Missing Completely at Random
MOR	Modulus of Rupture
MAUT	Multi Attribute Utility Theory
MIMIC	Multiple Indicators Multiple Cause
NAT	Normal Accident Theory
PLS	Partial Least Squares
QAA	Quality Assurance Agreement

QS	Quality System
RFID	Radio Frequency Identification
RH	Relative Humidity
SCOR	Supply Chain Operations Reference Model
SCRQ	Supply Chain Relationship Quality
SEM	Structural Equation Modelling
SME	Small and Medium-Sized Enterprises
SOP	Standard Operating Procedures
TI	Transfrigoroute International
USDA	United States Department of Agriculture
VIF	Variance Inflation Factor
WFO	World Farmers' Organization
WHO	World Food Organization

1 Introduction

1.1 Problem: Can Organizational Designs Impact on the Susceptibility to Disruptions?

Why do systems fail? Many researchers have investigated this question in areas such as nuclear power plants, air flight operations, or manufacturing plants.[1] The approach to investigate failures in an industry-specific context seems to be useful, since causes may be dependent on parameters, which may differ between industries.[2] A reason for selecting the industries above as fields of research is their complexity,[3] which makes the identification of causes of failures and the correct evaluation of critical situations more difficult (Perrow 1999). As another example, Dörner (1992) names the criticality of these systems, which means that accidents might cause death and/or severe harm to many people. Hence, on the one hand, causes of failures may differ from industry to industry, and on the other hand, the negative effects of errors differ in form and magnitude.

According to Helmreich, Klinect & Wilhelm (2001), the purpose of research on such failures is to enhance the robustness of systems. For such an analysis, Woolthuis, Lankhuizen & Gilsing (2005) suggest to make a distinction between failures due to the rules of the system and failures by humans, as humans cannot only cause failures but also resolve them. Additionally, Cook, Woods & McDonald (1991) stress the importance of differentiating between process and outcome since a defect might still be resolved if discovered before a shift to negative consequences occurs. This understanding implies that in case of undiscovered defects, a performance failure results, thus the actual outcome is different from the intended outcome, yet that it could have been prevented.

Analyses of failures in different industries resulted in the perception that even though the specific failures might have been different between several accidents, the patterns leading to the negative consequences of errors were similar. For example, frequently not only one defect occurred, nor were the failure-causing factors attributable to being either purely human, or technological. Furthermore, these failures occurred repeatedly in situations, were the system state and the normal workflow was amended (e.g. for maintenance) (Dörner 1992; Reason 1995; Perrow 1999). Thus, failures seem to occur more frequently when the system shows vulnerabilities in its processes.

Another industry, which reveals considerable criticality and complexity in its systems, is the food industry. Especially cold chains for temperature-sensitive products have been identified as incorporating a significant complexity (Trienekens & Zuurbier 2008; Vega 2008; Fritz &

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1 E.g. Rasmussen & Vicente (1989); Reason (1990); Dörner (1992); Reason (1995); Misumi, Wilpert & Miller (1998); Kletz (1998); Perrow (1999); Klinect, Wilhelm & Helmreich (1999); Helmreich (2000); Kjellen (2000); Helmreich, Klinect & Wilhelm (2001); Ornitz & Champ (2002); Dhillon (2007); Clarke et al. (2008).

2 For some examples see: Reason (1990) and Reason (1995).

3 Complexity in this context refers to the large number of agents in a system and the number of relations between these agents; see e.g. Dörner (1992); Hülsmann et al. (2007).

V. Brenner, *Causes of Supply Chain Disruptions*,
DOI 10.1007/978-3-658-08662-6_1,

Schiefer 2009). In today's cold chains, the contamination of food at one production stage can be critical to many people, as the market, especially in developed countries, is highly centralized and dominated by a few multinational food producers (Lyson & Raymer 2000). Their products are distributed to many retailers in different regions and countries, extending the radius of damage. Therewith, failures in the system of one food manufacturer can harm many people. Additional challenges arise in the case of temperature-sensitive products, such as fruit, vegetables, but also vaccines, as variations in temperature during transport can have significant negative effects on the products transported (Bogataj, Bogataj & Vodopivec 2005).

Furthermore, similar to other critical industries, as for example the pharmaceutical industry (Backhaus 1983), the food industry involves a broader class of stakeholders, including regulatory bodies and security agencies. According to the failure classification framework by Woolthuis, Lankhuizen & Gilsing (2005), thereby also the probability of failures is enhanced, simply because a wider range of rules exist. Furthermore, even though there are some major players in food production and retail, many actors are involved along the cold chain, due for example to the globalization of sourcing of food products and ingredients. This has transformed food supply chains to interconnected systems with a multitude of complex relationships (Trienekens & Zuurbier 2008).

In addition, food products increase the complexity of the systems due to their special characteristics. Among these are the heterogeneity of packaging and transport requirements of products, the huge variety in shipping volumes, due to e.g. seasonal variation, the continuous decay of quality attributes, which also depends on the applied processes, as well as the interaction between food compounds, packaging and equipment (Luning & Marcelis 2006). Therefore, food supply chains and especially cold chains can be considered as critical and complex systems, but do they also have industry-specific causes of failures and can negative outcomes be considered as failures?

In order to answer this question, in the following, three examples of deviations from planned outcomes will be described and analyzed.[4] For better comparability, they all refer to cases in the food industry.

Example 1: Specific causes of failures in global food systems

A recent study conducted for the Food and Agricultural Organization of the United Nations (FAO), revealed that approximately one-third of all food produced for human consumption is lost or wasted along the supply chain (Gustavsson et al. 2011). According to this study, food losses refer to "*... the decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption*" (Gustavsson et al. 2011, p. 2).

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[4] According to Yin (2009), case studies are useful if phenomena shall be investigated, which take place in large systems of great complexity, where rules are continuously and rapidly changing. Furthermore, according to Kromrey (2009) such qualitative studies are useful for exploratory research as is conducted here.

Especially fresh fruits and vegetables are susceptible to such losses (Parfitt, Barthel & Macnaughton 2010), which can be attributed to the following reasons: firstly, fruits and vegetables are of a perishable nature, which implies that shelf life is limited by **time** and may be further reduced by exposing the fruit or vegetable to wrong **temperatures** (Nunes et al. 2009). Furthermore, fruits and vegetables are also sensitive towards the **relative humidity** (RH) of the surrounding air, which should be kept high in order to avoid moisture losses and wilding of the produce (Zhang 1997). However, not only the environmental conditions play a role in the maintenance of shelf life, but also the **physical handling**, as waste due to mechanical injuries may be a large contributor to the entire food waste (Nunes et al. 2009). These and other factors have to be considered during handling of fruits and vegetables in the entire food system. If the system does not comply with these constraints, major losses may occur.

The FAO study estimated food losses for several agricultural food commodities in different regions of the world. On average, the following loss rates for fruits and vegetables could be observed for each step of the commercial food system:

Figure 1: Global average losses of fruits and vegetables from farm to fork

Agricultural production	**Postharvest handling and storage**	**Processing and packaging**	**Distribution**	**Consumption**
10-20%	4-10%	2-25%	8-17%	5-28%

Source 1: own illustration; data from Gustavsson et al. (2011)

The types of losses or waste are grouped according to the part of the food supply chain in which they occur, hence agricultural production, postharvest handling or storage, processing, distribution (supermarket retail) and consumption.

Regarding the findings of the FAO study, it becomes obvious that there are significant losses of fruits and vegetables in the food system. These occur not only in some parts of the supply chain, but in all parts. Nevertheless, there are considerable differences between loss rates for the same stage of the food system in different regions of the world. The differing loss rates could be an indicator for a varying degree of efficiency in the food system and therewith for potential loss reductions. For example, fruits and vegetables losses in processing and packaging in developed countries are estimated by Gustavsson et al. (2011) to amount to only 2%, whereas in developing countries in Asia or Africa, about 20-25% of the harvest is lost in this part of the chain.

Furthermore, the study provides information about the causes of food waste, which are for example:

- Inadequate forecasting of demand
- Poor storage facilities

- Lack of infrastructure
- Errors during processing
- Damaged packaging
- Damage during loading, transport and storage
- Rough handling
- Unsanitary conditions
- Lack of processing facilities (Gustavsson et al. 2011, pp. 10–14)

Regarding the numerous causes of food waste, it becomes obvious that a significant amount is lost not only because of natural and unavoidable decay, but due to errors occurring along the supply chain. This implies also economic losses for the parties in the food system, as for instance in the US, food waste from farm to fork amount to about US$ 90 to US$ 100 billion per year (Williams 2004). Several other studies support these findings, indicating that firstly, the amount of food waste is substantial in all segments of the supply chain, and secondly that a considerable part of these losses could be prevented by adequate food supply chain management.[5] Subsuming this example, causes of defects are quite specific due to the nature of the products. However, the reasons why defects amounted to failures cannot be analyzed based on this example as the level of abstraction precludes this information, wherefore it will be analyzed in the next example.

Example 2: Vulnerability of processes in food systems

Fraud is a frequent and sensitive issue in the food industry. On the one hand, cases of fraud are published every year (BWV 2011), and on the other hand, the loss of trust by consumers may have a significant negative impact on sales and reputation of companies (Luo 2010), even though the case might have been committed somewhere else in the food supply chain, or even in other food systems.

One example is the dioxin scandal in Germany at the beginning of 2011. Back then, a producer of ingredients for animal feed illicitly mixed its feed fat with fatty acid in order to cut costs (Brandt et al.). This fatty acid was, according to its supplier, a biodiesel producer, only dedicated for technical utilization purposes and was found later on to be contaminated with dioxin (Marquart 2011). Even though the producer effected in 2010 three self monitoring tests, where the legal threshold for dioxin was breached every time, the contamination of the animal feed was not reported to the authorities, nor the deliveries to the customers stopped (Brandt et al. n.d.). In consequence, about 3,000 tonnes of dioxin contaminated feed fat was delivered to about 25 producers of animal feed in eight federal states in Germany, which led to the contamination of 150,000 tonnes of animal feed (Marquart 2011). After feeding the animal feed to pigs, chicken and turkey, dioxin contaminated meat and eggs got into the human food chain.

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[5] E.g. Ward (1996) cited in: Cheke & Ward (1998); Engström & Carlsson-Kanyama (2004); Nunes, Emond & Brecht (2006); Vermeulen et al. (2006); Nunes et al. (2009).

This caused losses of billions of Euro, because several hundred thousand eggs had to be destroyed, consumers avoided buying animal products, and 5.000 farms were temporarily closed (Der Spiegel n.d.).

That the transaction between the producer of biodiesel and the producer of feed fat has not been noted, even though the producer was a member of a private quality control system (QS), has several reasons: first of all, the transaction was effected indirectly through a Dutch trader, who deals with animal fat as well as fatty acids. This indirect trade obscured the relation between the two companies, who would normally not work in the same system. Secondly, producers of ingredients for animal feed were the first link of the controlled food system, thus no attention was paid to their suppliers. This means that inadequate products could enter the food system without notice. Thirdly, the company was audited only once by QS during the year 2010. So, whereas the company was certified as being compliant with QS, little attention was paid to control this statement.

That the contamination has not been detected earlier is also due to the regulatory structure of the food sector in general. For example, there is no standardized list of allowed ingredients in animal feed across Europe (El-Sharif 2011). In consequence, some ingredients might be allowed in some countries, while being forbidden in others. Since supplies can be purchased worldwide and animal feed supply chains are highly complex with a multitude of actors involved (Marquart 2011), the possibilities to control the entire supply chain by local authorities and to assure the quality of the end product is limited. Furthermore, according to Brandt et al., companies involved in feed production tend to diversify their business and transport units are also used for other products, the animal feed supply chain is prone to contamination, resulting in contaminated food destined for human consumption. And finally, up to the dioxin scandal the audits of the responsible German authorities were mainly concerned with food production plants and not with animal feed production plants (Brandt et al.).

Thus, even though there are private quality control systems as well as official regulations, audits, and laws in place to assure the innocuousness of human food, the planned flows in the food system can be breached without notice, resulting in highly vulnerable processes. Furthermore, it is the complex interaction of several defects, which result in the negative shift in consequences, what Cook, Woods & McDonald (1991, p. 15) call a "*going sour incident*". How critical such failures in food systems can become shows the next example.

Example 3: System failures

An example for a recent food scandal without obvious intentional fraud was the outbreak of enterohaemorrhagic Escherichia coli (EHEC) in Germany in May 2011. This case represented a major challenge, not only to German authorities, but also to European ones. First of all, this was the first outbreak of this particular germ, so very little information regarding its resistance and behaviour was available. EHEC is a bacterium, which normally resides in the intestinal of humans and animals, and which can be conferred via contaminated food (BfR 2011). However, it was not possible to trace back the source of contamination, where the planned product flow had been breached. Secondly, the product is part of a multitude of food products, such as salads (RKI 2011), spices, and food additives (BfR 2011). In consequence, it took a lot of time and effort to trace back the EHEC infections to their origin.

Within two months, approx. 3.850 people were infected and about 53 patients died (RKI 2011). During several weeks, information on which food product caused the disease as well as on the origin of the contaminated product varied. After having firstly accused cucumbers from Spain being the cause of the epidemic, finally fenugreek seed scions from Egypt were identified as the germ carrier (Kwasniewski 2011). In all, 37 tonnes of potentially contaminated fenugreek seeds had been exported to Germany and from there been distributed to at least 14 other states (BfR 2011).

The outbreak of EHEC had considerable implications for farmers across Europe, seed producers in Egypt, but also for consumers in Germany. European farmers are claiming more than 210 million Euros of losses, due to the preventive destruction of food products and the slump in demand of many different kinds of vegetables (Kwasniewski 2011). The European Union banned all Egyptian seeds as well as beans to prevent further outbreaks and consumers in Germany were unsettled, not only because of the risk of infection, but also because of the inferior crisis management and communication by official authorities (Teevs 2011).

The detection of the source of infection was complicated by several factors. First of all, the product was only causing infections as raw scions, which are frequently used in mixed salads. The mix of different vegetables from different countries and suppliers made the detection of the source of infections considerably more difficult. Furthermore, the breeding from a seed to a scion provided a different end product, which was only in its raw estate damaging to human health. This implies that products from the same charge may have caused harm to humans or not, depending on their final state, which is intended to make the food system safe and transparent. Thus, the complexity of the supply chain, caused for example by the number of potential infection sources, the number of agents involved, the different authorities involved, and the different processing stages of the product, resulted in the inefficiency of the traceability system for food products. Hence, food systems can be considered as critical systems, since the effects of errors can be devastating, even though they differ in form and magnitude.

Synopsis of the Examples

The examples given above highlight the diversity of issues which may occur in supply chains vital for the society. These concern for instance the type of product affected (animal product or plant product) and the type and severity of negative outcome (economic losses or health risk). Nevertheless, the three examples also show some similarities regarding how the failures evolved. In the FAO study for example, frequent causes for food waste are mentioned. These failures did not only occur in one food system, but repetitively re-occur in many food systems all around the world. So, whereas the negative results as well as the causing defects are known, these defects are not eliminated. Also the other two cases show some similarities regarding the types of defects. In both cases, food products were contaminated, showing a lack of protection. Additionally, the lack of information collection within the supply chain was a major contributor to the negative outcome and occurred repetitively, i.e. at more than one node in the system. So, even though the situation and the system were different from each other, the same types of defects occurred repetitively.

From what has been learned from other industries, an error committed by one person frequently does not lead directly to a consequential negative outcome. For example, Flin, O'Connor & Mearns (2002) state that accidents in surgical medicine are frequently due to the communication and teamwork, thus due to interaction. They also cite an example from the aviation industry, where a crash could have been prevented, if the pilot would have been informed appropriately by the crew about a technical error. In both cases, the negative outcome is due to some kind of multi-causal interaction, and is only indirectly caused by the original technical or human error. However, what all these cases have in common is the negative effect of errors, which significantly decrease the performance of the system.

In the literature on supply chain management, such failures are also known as supply chain disruptions (e.g. Wagner & Bode 2008). Disruptions are a phenomenon, which is increasingly gaining attention in the literature, as will be shown in 2.2.2. As a consequence of such disruptions, the achievement of the main logistics objectives[6] is imperilled. In the context of food supply chains for perishables, hence time and temperature sensitive products, the provision of the right quantity and the right quality of products is directly related to the maintenance of optimal conditions from farm to fork. Thus, disruptions do not only occur by delaying, destroying or impeding the product and information flow, but also by interrupting the temperature maintenance, also known as cold chain ruptures (Coton et al. 2011). In consequence, disruptions may also be caused by failures to maintain surrounding conditions as required.

The occurrence of disruptions can also be seen in the three examples above. In all three cases, some defects caused destruction or contamination of products, and/or the information flow was impeded. In the first example, defects in checking products and providing information led to contamination of products and lack of information flow. This could only be realized as adequate quality control procedures within the company, but also at its customers were lacking. In the second example, errors led to food wastage due to some kind of wrong handling, combined with the lack of adequate protection of the product and suitable infrastructure. In the third example, the contamination of seeds may also only lead to the negative consequences, as apparently suitable quality controls are lacking. Hence, it seems as if the negative effects of errors are only realized, if their occurrence interacts with some vulnerable organization of the processes concerned with the product or information flow, which then leads to the disruption.

[6] The 7Rs of logistics are: right product, right quantity, right quality, right time, right costs, right place, right knowledge (e.g. Jetzke 2007; Ross 2011).

In summary, there is a practical need to analyze the occurrence of disruptions in supply chains. As Chmielewicz (1979) asserts, research is always a combination of theoretical and practical purposes, wherefore also the relevancy of the research question has to be shown for both perspectives. Therefore, section 1.2 will focus on the theoretical relevance.

1.2 Relevance: Theoretical Gaps on Organizational Design and Disruptions

In order to show the theoretical relevance of the research question, the related research in the fields of failures/disruptions, and organizational design has to be illustrated, to reveal its limitations in explaining the causal relation between the variables. Thereby, the contributions are structured according to the focus of investigation into three categories, namely organizations in general, supply chains, and food systems.

Organizational Design

According to Ansoff & Brandenburg (1971), organizational design is the decision making by companies on their organizational structure under considerations of the organizational strategy and environmental constraints. This contingent optimality of organizational structures has been taken up in empirical research, but led also to the theoretic stream known as contingency theory (e.g. Wolf 2008; Kieser & Ebers 2006).

In a comparative analysis of six organizations, Lawrence & Lorsch (1967) tried to assess the effect of organizational design on economic performance. They come to the conclusion that those organizations where integration and differentiation of the organizational structure fit the requirements by their respective environments performed better.

Based on data from 34 medium-sized firms, Gordon & Narayanan (1984) tested whether information systems and organizational structure are affected by environmental constraints. They conclude that those companies facing higher environmental uncertainty tend to seek increasingly more information from outside the company, transforming the company structure more and more into an organic structure. Hence, in these two examples, evidence is found for the influence by the environmental conditions on the organizational design.

The same can be reasoned for the influence of organizational strategy, as the next two examples indicate. In an empirical analysis of the effects of the kind of technology used on the organizational structure, Hickson, Pugh & Pheysey (1969) come to the conclusion that the technology only has an influence on those organizational variables, which are concerned with the workflow. The extent of effects was found to differ considerably with different sizes of companies and different ratios of employee-manager relations.

In a survey in the savings and loans industry, Jennings & Seaman (1994) aimed for answering the question, how the choice of a strategy and structure affects performance of companies. They found evidence for a better performance if companies chose a static structure when a defender strategy was followed or a dynamical structure when a prospector strategy was followed.

These findings indicate that firstly, organizational structure depends on constraints, and secondly, organizational design has an impact on performance. However, the unit of analysis in this research is mainly a single company. The question, how the organizational design that includes several companies affects the performance has therewith not been answered, yet.

This topic is part of the **supply chain** management literature. Wathne & Heide (2004) for instance assess the governance of relationships in supply chain networks of the fashion apparel industry. Based on transaction cost theory, they build a theoretic framework for how to deal with uncertainties in vertical relationships. Furthermore, they argue based on network literature that the need for flexibility or relationship modification of a manufacturer in his relation to retailers does not only depend on the governance of this relationship, but also on how the relationship towards its suppliers is designed. In order to allow for flexibility of the arrangements with suppliers, two governance mechanisms were identified: the choice of suppliers shall be based on formal supplier qualification programs, and the incentive structure shall be based on long-term gains instead of short-term profit payoffs of potential opportunism. They come to the conclusion that firstly, relationships and the ability to adapt to uncertainties are indeed interdependent in larger networks, and that the governance is far more complex, as to be managed by the two mechanisms identified. Therefore, they call for additional research into the properties and effects of alternative mechanisms of relationship governance in supply chain networks.

Fynes, Voss & de Burca (2005) examine the impact of supply chain relationship quality on quality performance. Based on several theoretical frameworks,[7] and different research streams,[8] they come to the conclusion that paradigms to explain the nature of supply chain relationships converge to some common components. These components, namely trust, adaptation, communication, dependence and interdependence, commitment and co-operation are combined to what they refer to as supply chain relationship quality (SCRQ). They come to the conclusion, that the SCRQ indeed has a positive impact on quality, and that in order to enhance it companies should focus on the management of supply chain relationships. Thus, the kind of relationship was found to have an impact on quality performance, yet based on an eclectic approach.

The role of organizational design has also been studied in the context of **food systems**. Loader (1997) for example bases his analysis on transaction cost theory. He stipulates that the configuration of exchange relationships is determined by the nature of transaction (i.e. standardized, occasional non-standardized, or recurring non-standardized) and the characteristics of investments (non-dedicated, dedicated, or input characteristics mixed). Based on the two criteria, he differentiates between market-based, trilateral, and bilateral/unified governance of the exchange relationship. He applies this framework to an international supply chain of fresh products and comes to the conclusion that due to asset specificity and uncertainty prevalent in

7 For instance transaction cost theory, political economy theory, and social exchange theory.
8 Such as relationship marketing, operations management, supply chain management and logistics.

this supply chain, a vertical integration can be observed. In consequence, the nature or type of transaction seems to have an effect on the organizational structure of exchange relationships.

The role of asset specificity in the design of food systems has been affirmed by Ménard & Klein (2004), who compare network designs for different agricultural products. Based on data from Europe and the US, they observe that during the last century, the production, processing and distribution of food as been significantly consolidated, even though farming remains a mainly family-owned business. The structure of the food sector, together with the requirements for vertical coordination and quality control has led to a shift away from spot-market exchanges, to more vertical integration and long-term contracting. However, numerous forms of vertical coordination exist, which, according to the authors, can be explained by transaction cost considerations. Food products, which are subjects to mechanization, quality standards, and physical asset specificity, as well as site and temporal specificity, are controlled more closely than others. Thus, the degree of processing, the criticality to health, and the product characteristics such as its perishability all seem to play a role in the design of the food systems.

However, all these examples are rather concerned with how partners cooperate with each other on a rather abstract level. The question, how the organizational structure can be related to the occurrence of disruptions as therewith not been answered, yet.

In summary, the relation between interface design and performance has been studied in detail in the literature in general, as well as in supply chain management literature, and even in the context of food systems. However, a connection to the phenomenon of disruptions and systematic errors is lacking. Furthermore, the analyses mainly remain on a relatively abstract level and employ case-study research.

System failures

The research on failures has developed as a research discipline of its own, even though up to now, a discipline-encompassing and thorough illustration of perspectives and results of the research, as well as a general taxonomy, is lacking (Weingardt 2004). On the **organizational level**, different research disciplines analyzed causes for break-downs, catastrophes and accidents (Kletz 1998; Kjellen 2000; Ornitz & Champ 2002; Perrow 2006; Dhillon 2007; Hofmann 2008). Perrow (1999) for example analyzes accidents in large scale process plants. Based on his observations, he comes to the conclusion that accidents happen due to the complexity of interactions and the tight coupling of elements in complex systems. Furthermore, he acknowledges the impact of systematic barriers and organizational design on the creation of poor performance in complex systems, such as air transport systems or marine transport systems.

Dörner (1992) comes to a similar conclusion in his analysis of a reactor catastrophe. Additionally, he stresses the fact that the explosion was not due to only one defect, but due to a series of interconnected errors. He argues that the unintended secondary effects of actions were not observable and that their joint occurrence led to a chain reaction of wrong decisions and system changes, which finally resulted in the catastrophe.

In the analysis of major oil spills and resulting natural catastrophes, Ornitz & Champ (2002) estimate that in the end about 80% of these spills were due to human error. However, as root cause, they also name other causes, such as lack of maintenance of ships, lack of training, and reduction of workforce. Hence, human errors have been found to be the ultimate cause of such catastrophes, but their occurrence was already inherent in the systems.

The human factor is also widely studied and centralized around the study of human beings and their interaction with products, environments, and equipment in performing tasks and activities (Czaja & Nair 2006). Research is based on a multidisciplinary approach comprising psychology, engineering, information science, social science and economics (Badke-Schaub, Hofinger & Lauche 2008). Since this field of research encompasses many different disciplines, in the following some aspects from different fields will be highlighted.

A person-focused approach to explain errors and consequential failures originates from **psychology** (Reason 1995). In cognitive psychology, many errors are explained by the wrong retrieval of information, which has been obtained earlier, and which had been stored in the subconscious till it is needed. Since experiences and knowledge are not stored exactly as they are, friction losses occur which might lead to wrong actions when, based on this information, activities are executed later in time (Spencer 2000). Human errors are also analyzed for example in the error-mode-and-effect-analysis, which classifies human errors into: errors related to learning and adaptation, interference among competing cognitive control structures, lack of resources, and intrinsic human variability (Rasmussen & Vicente 1989). In the context of human errors, the systematic occurrence has been already observed as early as 1926, when Weimer (1926) stated that errors are not random, but are indicators for more deeply rooted defects. Hence, even though the human being is the one to commit an error, systematic errors do have a causal explanation.

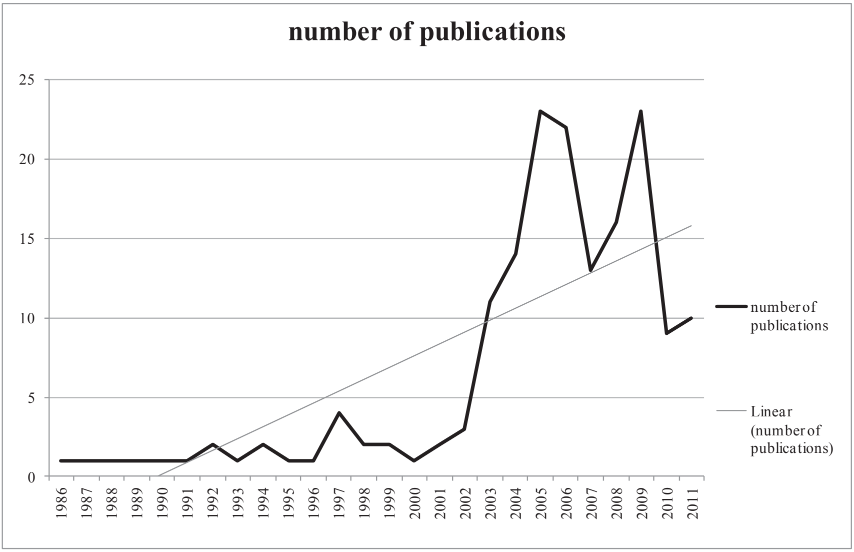
Errors are also closely investigated in **engineering** for the optimal design of human-machine interfaces (e.g. Vicente & Rasmussen 1992; Vicente 2002; Wilson 2000). For example, in the air flight industry, human errors in cockpits have been studied closely in order to prevent accidents. Klinect, Wilhelm & Helmreich (1999) for instance analyzed data from the Line Operations Safety Audits (LOSA) of different airlines and divide errors of flight crews into intentional non-compliance, procedural errors, communication errors, proficiency errors and operational decision errors. They come to the conclusion that not all errors result in consequential negative outcomes, that they have different frequencies of occurrence, and that different airlines tend to be unequally exposed to errors. Thus, the amount and magnitude of causes of errors seems to depend on the specific organization, resulting in different degrees of susceptibility to errors. Furthermore, even though errors were committed by people, the data revealed different levels of vulnerability, hence the extent of damage caused by errors. These findings support the argument of other authors, who argue that the underlying system structure should be designed in such a way, as to prevent the negative outcome of human errors (Rasmussen & Vicente 1989; Reason 2000; Thomeczek & Ollenschläger 2006).

According to Reason (1990), a person's active failure only results in a negative outcome, if the system design, consisting of the layers humans, technologies and organization, are arranged in such a way that latent error provoking conditions of all three components overlap each other so that all safety mechanisms fail. This so-called Swiss cheese model has been applied to many different systems, such as in anaesthesia, nuclear power plants or air traffic control centres (e.g. Reason 2000; Grube, Schaper & Graf 2002). Reason (1997) comes to the conclusion that an effective safety culture needs to be based on reports, fairness, flexibility and a willingness to learn.

The importance of system's design for the occurrence of human errors is also supported by other authors. For example, Dörner (1992) presents some simulation cases, in which the behaviour and decision making of testing groups during the management of fictive villages was analyzed. He observes that errors in the decision making of humans were mainly caused by the inability to capture the complex interactions of causal relations, and the neglect of signs which were indicating effects that did not fit the assumptions of participants on causal relations. Hence, error prevention involves a temporal dimension, namely to learn from past errors and to use this knowledge for an active error prevention and mitigation of effects. Furthermore, human error and system defects seem to reinforce each other and jointly lead to failures. Therefore, also both should be considered in the analysis of failures.

In the area of **supply chain** management research, interest in failures or, more specifically, disruptions is still relatively young but on the rise, as can be seen in Figure 2.

Figure 2: Evolution of publications on supply chain disruptions



Source 2: own illustration; for further details on the review see section 2.2

According to Stevens (1989), who investigates supply chains in the manufacturing industry, the scope of a supply chain begins at the source of supply and ends at the final point of consumption. It comprises not only the physical movement of goods, but also relates to other activities, like supplier management, purchasing, materials management, customer service and information flow. Furthermore, Stevens points out that all these activities are interdependent and that if one of them fails, the supply chain is disrupted, which creates poor performance and jeopardizes the effectiveness of the supply chain. In order to avoid such disruptions he suggest that the partners in the supply chain should work together in a closely manner, to create an integrated supply chain.

This view on supply chain disruptions and solutions is also issued by Geary, Childerhouse & Towill (2002, p. 53) who aim for "*the seamless supply chain*", which is constituted by a perfect flow of information and materials, and all supply chain partners thinking and acting as one single entity. Based on their research on supply chains in the automotive industry, they come to the conclusion that safety mechanisms have to be established to protect the supply chain. These safety mechanisms are ultimately trying to tackle the uncertainty related to potential disruptions. In order to reduce uncertainty in the areas of process, demand, supply, and control, supply chain partners shall strive for the integration of the entire supply chain.

Based on a cross-sector empirical study and on systems theory, Peck (2005) argues that in order to reduce the vulnerability of a supply chain to risks, functional goals of supply chain management have to be linked to decisions on the organizational design and business strategy. She cites many causes for supply chain disruptions, stemming from company-specific, supply chain specific or industry specific sources. However, the understanding of disruptions is again reduced to a disruption in supply, without considering any other kind of disruptions, and without any further harmful effects outside of the companies in the supply chain.

While the understanding of supply chain disruptions from the sources above is still more related to balancing supply and demand, other authors are explicitly addressing the possible intervention of some external incidences or operational contingencies as causes for supply chain disruptions. Paul (2008) for instance names as causes for supply chain disruptions three major classes of risks, being operational contingencies such as equipment failures, natural hazards, and terrorism or political instability. He suggests that in order to manage these risks managers first need to identify the vulnerabilities of their company.[9] However, given the aim to derive general assumptions on causal relations, the focus will be narrowed down to a specific industry to learn more about its vulnerabilities do disruptions.

A meta-analysis of research on causes for disruptions by Hülsmann & Brenner (2011) reveals many contributions dealing with disruptions in **temperature-sensitive food supply chains**. These papers indicate that disruptions occur quite often in cold chains, and that their negative effects are substantial. Thereby, the lack of transparency, a multitude of actors along the supply chain and differing requirements by products, but also by regulations are frequently cited system defects causing disruptions. At the same time, the lack of staff, lack of education of staff and carelessness by employees is frequently cited as human errors causing disruptions. However, they mostly report results of case studies and do not analyze in detail the causal relations between the disruption and the cited errors causing this disruption.

Nevertheless, many authors confirm the important role of the supply chain design and especially of the interfaces in the diminution of disruptions in the information, product and temperature flows. Examples for disruptions at interfaces are for instance the exposure of fruits and vegetables to ambient temperatures during loading and unloading, or the delay of information forwarding to the customer. Such delays or the refusal of information forwarding has also been observed in the examples above, while the loading process has also been mentioned as cause of disruptions by Gustavsson et al. (2011).

In summary, the interdependence between system design and the occurrence of failures has been recognized in the literature. Also disruptions are an important topic and their reasons have been investigated in many different settings. The role of interface design as a contributing factor to disruptions is also acknowledged. This includes for instance tight coupling of processes, complex interactions, and uncertainty during decision making. However, research on disruptions seems to either focus on a specific case, where insights are gained on the actual evolvement of one disruption. Or research is on a very abstract level, where generic insights

9 For a detailed overview on understandings of disruptions see section 2.2.2.

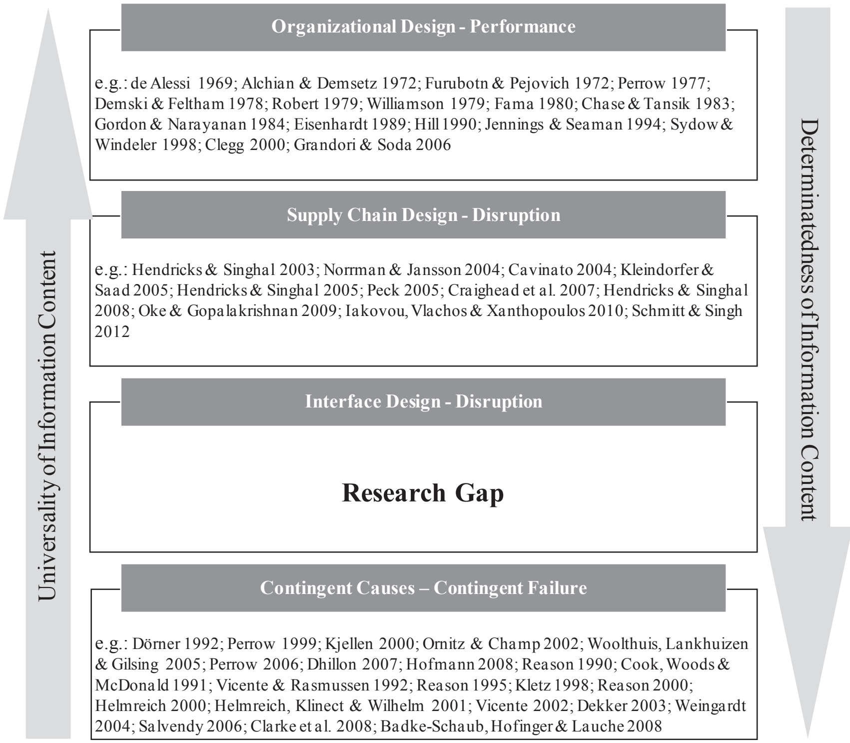
are gained, yet where the process remains a black box. Therewith, no general causal relations between the interface design and the occurrence of disruptions can be deduced.

According to Chmielewicz (1979), information content of research results varies in two aspects, namely regarding the universality of statements, and their precision. There are therefore two options to increase information content of research, either by increasing the universality of statements, or by increasing their preciseness. Trying to increase both at the same time will is however limited, as therewith also the risk of false statements rises (Chmielewicz 1979). In the case of failure research in general, already a wide body of insights has been gained, which are generic and explain the evolvement of failures. However, in this case, a single company or even department or team stands in the focus of research, which might be more homogenous in the set of rules as when transaction partners are evolved. Hence, an extension of analysis regarding interaction effects is currently still required, to be able to explain failures in more settings. Therefore, this research will try to bridge the gap between case study-based precision of causes for failures, and general applicability of insights on optimality of organizational design.

Therefore, there is a need to identify, describe and explain causal relations between interface designs and the occurrence of disruptions in supply chains and to show starting points for their improvement.

An overview on contributions in the related research areas, and the identified research gap can be found in Figure 3.

Figure 3: Overview on relevant literature and current research gaps



1.3 Aims: Explaining the Occurrence of Disruptions Based on Organizational Design

As has been highlighted in the previous sections, the susceptibility of supply chains to disruptions seems to differ depending on their configuration, indicating potential for a reduction of disruptions. Nevertheless, up to now, research on disruptions and their causes in temperature-sensitive supply chains, such as food chains is scarce.[10] Therefore, based on the assumptions stipulated in section 1, the overarching objective of this thesis is to identify, describe and explain causes of disruptions at interfaces for the example of cold chains.

According to Bea & Haas 2001, scientific research in the field of business economics has the purpose to develop tools that help to describe, explain and design companies in the context of

[10] See section 2.2 and 2.3.