RESEARCH

Verena Brenner

# Causes of Supply Chain Disruptions

## An Empirical Analysis in Cold Chains for Food and Pharmaceuticals

Springer Gabler

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Hannover, Germany

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## 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 &

---

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).

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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.

[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