Decision Support for Critical Infrastructure Disruptions: An Integrated Approach to Secure Food Supply

Thomas Münzberg
Institute for Nuclear and
Energy Technologies,
Karlsruhe Institute of Technology
thomas.muenzberg@kit.edu

Ulrich Berbner
Supply Chain and Network Management,
TU Darmstadt
berbner@bwl.tu-darmstadt.de

Tina Comes
Institute for Industrial Production,
Karlsruhe Institute of Technology
comes@kit.edu

Hanno Friedrich
Institute of Traffic and Transport –
Chair of Commercial Transport
friedrich@verkehr.tu-darmstadt.de

Wendelin Groß
4flow AG
w.gross@4flow.de

Hans-Christian Pfohl
Supply Chain and Network Management,
TU Darmstadt
pfohl@bwl.tu-darmstadt.de

Frank Schultmann
Institute for Industrial Production,
Karlsruhe Institute of Technology
frank.schultmann@kit.edu

ABSTRACT

Supplies of food and water are essential in disaster management, particularly in the very early chaotic phases when demand and available resources are highly uncertain, information systems are disrupted, and communication between communities, food suppliers, retail and emergency authorities is difficult. As many actors and organisations are involved in ever more complex food supply chains, cooperation and collaboration are vital for efficient and effective disaster management. To support decision-makers facing these problems, this paper introduces a scenario-based approach that integrates simulation of disruptions in food supply chains, and qualitative expert assessment to develop consistent scenarios that show the consequences of different strategies. To choose the best individual measures for all relevant actors and to compare it with the best overall strategy approaches from multi-criteria decision analysis are used.

Keywords

Participatory Multi-Criteria Decision Support, Food Supply Disruptions, Supply Chain Risk Management

INTRODUCTION

Natural or man-made hazards like pandemics, heat waves, floods or snowstorms may cut off the population from essential supplies such as food or water. Reasons may be direct business disruptions (e.g., destruction of a production sight), indirect effects such as critical infrastructure (CI) failures (e.g., disruption of road, railway, or air traffic) or trade infrastructure disruptions (e.g., closure of food warehouses and stores).

Disasters such as Hurricane Katrina in 2005 (Sobel and Lesson, 2006) illustrated the challenges in providing food to the population. Particularly in the immediate aftermath of a disaster, uncertainty is overwhelming, and demand levels, available supply and resources and infrastructures are unknown. In these situations, emergency measures entail the actions of the food and retail industries (maintaining or resuming their services) and the

Emergency Management Authorities (EMA) aiming at ensuring the supply of goods to the population. However, the complexity, dynamic development and interlacement of supply chains are increasing, forestalling the possibility of referring to pre-planned procedures and practices. At the same time, emergency response of private households and individual retail stores is limited because of reduced inventory levels. Due to the potential disruption of information and communication systems and emerging patterns of responsibilities, collecting and sharing information as well as aligning emergency response measures between the affected communities, food suppliers, retail and EMAs are difficult.

Current research in the area of risk/crisis management and decision support for risk/crisis management includes

- General methods or strategies for elevating supply chain robustness or resilience (Vlajic, van der Vorst and Haijema, 2012),
- Simulation models for evaluating the adverse effects of supply chain interruptions and the effects of possible counter measures (Wilson, 2007)
- Scenario based methods to cope with unpredictable situations (Wright and Goodwin, 2009) and
- Multi-criteria decision analysis (MCDA), which is aiming at supporting decisions with conflicting objectives (Hodgkin, J., Belton, V. and Koulouri, A., 2005).

The approach presented in this paper, builds on existing research from the fields outlined above, by creating an integrated decision support framework for food supply chain (FSC) disruptions. To take into account the typically very heterogeneous information stemming from diverse sources, quantitative and qualitative assessments are integrated into a scenario-based decision support tool, which allows for simulating possible counter measures in various crisis scenarios. The framework will address decision makers from private and public authorities and it will integrate different types of adequate methods and tools for decision support , which facilitate collaborative decision-making and consensus building.

The paper starts with a brief introduction of food supply chains and an overview of existing approaches to Food Supply Chain Risk Management (FSCRM). Essential requirements will be derived for effectively and efficiently handling adverse events that might lead to supply shortages. Afterwards, different simulation approaches as well as different aspects of decision models are being discussed as potential elements of a decision support approach. The approach itself will be presented in the last section of the paper.

MANAGING DISRUPTIONS OF FOOD SUPPLY CHAINS

Trends like globalisation and growing market volatility have increased the vulnerability of supply chains in general (Pfohl, Gallus and Köhler, 2008). FSC are characterized by strict shelf life constraints, long lead times as well as production seasonality, legislation for food production/handling and specific requirements for logistics processes like warehousing and transportation (van der Vorst, Beulens and van Beek, 2005). As a consequence of the on-going need of performance increases, FSC have become leaner e.g. by eliminating none value adding activities and reducing inventory, which increased vulnerability in cases of supply disruption (Vlajic, van der Vorst and Haijema, 2012).

Supply Chain Risk

Risk to supply chains is typically valued as product of the two factors probability of occurrence and consequence of a hazardous event or as an aggregation of hazard, exposure and vulnerability (Merz, Hiete, Comes and Schultmann, 2012). As modern supply chains are interdependent, the impact of risk events can typically not be contained locally and originally small regional events may affect the whole supply network (Pfohl et al., 2008). Most SCRM frameworks start with the identification of geographically and temporarily restricted hazard scenarios, such as an earthquake in a given region (Hiles, 2010). This event-based approach may lead to the neglect of complex interdependencies, which are difficult to quantify and predict (Power, 2005). Along with the growing interdependence, the management of risk, by implementing SCRM strategies that increase the robustness and resilience against adverse events, must be adapted and understood as a supply chain wide process (Christopher and Peck, 2004). As risks cannot be foreseen nor predicted, pro-active scenario-based approaches (Klibi and Martel, 2012) will become a central part of the suggested decision support approach.

The Need for Collaborative Decision Support in Food Supply Chains

Different actors like food industries, retailers and logistics companies as well as various EMAs are involved to provide food for a disaster-affected region. Although effective collaboration and aligned strategies are essential to manage major disasters (Oloruntoba, 2005), there are several obstacles: First, EMAs and FSC-actors are usually not interfacing in day-to-day business. Second, each actor follows different objectives, and the information, which is typically distributed asymmetric among the actors, may cause problems of trust (De Walle and Turoff, 2008). According potential FSC disruptions in disasters, various questions arise:

- What are the consequences of a disaster event to the FSC Network and how can disaster lead to FSC disruptions and an insufficient food supply? Are consequences isolated in a disaster-affected region or do they have effects to other regions, too? What strategies can enhance the robustness of FSC?
- Which actor is responsible for what part of the FSC? How are the interdependencies between the actors and how are the actors affected when there is one or more disruption in the supply chain?
- How can EMAs facilitate the business in the FSC and what kind of action needed from EMAs to secure sufficient food supply? What are robust strategies to keep a sufficient food supply in disasters?

To overcome these obstacles decision processes have to be defined and well-understood, and synergetic potential of aligning public and private measures have to be made transparent by the suggested decision support approach. Today, there is no systematically framework to find answers to these questions.

BUILDING THE FOUNDATION OF THE INTEGRATED DECISION SUPPORT APPROACH

To analyse consequences of supply chain disruptions quantitative modelling methods and scenario techniques for decision support will be used. In both areas research has been done that can be built on, the application for the analysis of decision support in case of disruption of critical infrastructure disruptions is however new.

Supply Chain Modelling and Simulation

Although a lot of information on the food supply sector is available, a full picture on food commodity flows, stocks and behaviour that is necessary for the analysis of consequences is missing. To our knowledge there is no logistics model that describes consequences of risks or crises on the collective food supply chains of a region. However, there are models from logistics, overall economic analysis and transportation research that are interesting in this context. In logistics and especially in humanitarian logistics consequences of risks on individual supply chains or networks are analysed. Prescriptive models try to optimize the logistics design, for example Simchi-Levi (2012) who determines the optimal level of flexibility of production networks. Descriptive models analyse the likely impact of events on supply chains, for example Wilson (2007) who analysis the impact of transportation interruptions. From the area of overall economic analysis, modelling approaches like the input-output Analysis (Leontief, 1986) and general equilibrium models (Bröcker, 1998) exist. General freight transportation demand models do not yet focus on the analysis of risks, however they are of interest since they describe the collective supply chains of a region. And in recent years there was a tendency in this area to include more logistics details (De Jong, 2012). For the area of food, the model of Friedrich (2010) stands out since it simulates logistics structures in the German food-retailing sector and gives estimates for all food commodity flows in Germany.

Decision Support in Crisis Management

In strategic risk management, decision makers usually have to consider various conflicting objectives under uncertain decision parameters (Comes, Wijngaards, Hiete, Conrado and Schultmann, 2011). For their ease of use in structuring complex problems and building consensus methods from Multi-Criteria Decision Analysis (MCDA) have often been used successfully to support decision-makers in emergency management (Geldermann, Bertsch, Treitz, French, Papamichail and Hämäläinen, 2009). The presented approach will apply existing research in the area of dynamic interdependencies in decision-making (Comes, 2013) to food supply chain disruptions. In addition scenarios have proven useful to take into account uncertainty in the evaluation strategies in risk and disaster management (Comes et al., 2011; Wright and Goodwin, 2009) and will serve as a framework to generate insights to the causes and the development of disruptions in the presented approach.

AN INTEGRATED APPROACH TO COLLABORATIVE DECISION SUPPORT

To maintain food supply in case of adverse events, FSC require the integration of actors (governmental organisations, NGOs or private industries) in various roles (logistics and distribution, production, etc.) to increase resilience and robustness while respecting the constraints and requirements of the original actors. This can be achieved by providing transparency to all decision makers involved concerning the possible development of a crisis and the effects of the implementation of selected counter measures. By making relevant information available throughout the FSC and reaching clarity concerning the objectives of the various decision makers involved, effective and efficient collaborative decision-making will be facilitated. To this end, we suggest a multi-level approach that supports the exchange of information, analyses the consequences of disruptions under various developments and facilitates consensus-building by following a participatory approach. Our suggested solution consists of four steps, which we will describe in detail below:

1) Analysis of the roles, responsibilities, and requirements of all involved actors; definition of feasible emergency management alternatives at an individual level; definition of feasible strategies;
2) Definition of food supply disruption scenarios for a given hazard event;
3) Consequence assessment quantifying the impact of disruption scenarios and different disaster management strategies via simulations and expert judgements; and
4) Ranking of collaborative disaster management strategies via MCDA.

At first, information about the *roles*, *responsibilities and requirements* of all involved actors are mandatory for any decision support system (Hodgkin, Belton and Koulouri, 2005). All actors have different interests, objectives and preferences that need to be considered to build consensus. Additionally, the legal and normative standards have to be taken into account. Finally, the individual options-for-action must be assessed and their compatibility must be tested as a starting point to define the overall disruption management strategy.

Secondly, various *disruption scenarios* must be defined. These scenarios model the triggering hazard event such as an earthquake or a hurricane, and the immediate consequences on CI and the demand for food supplies.

Thirdly, the *consequences* of the disruption scenarios are analysed. The disruption scenarios serve as input for food freight and logistics models to simulate realistic food supply chains and their behaviour during and after major disasters. Information from the simulation includes for example place quantity knowledge about manufactures, supplies, storages and their stocks. To take into account the overwhelming uncertainties about the emerging patterns and further actors, which are not part of day-to-day operations (e.g., NGOs), expert assessments and qualitative information is used to complement the scenarios. These assessments are also used to predict the demand patterns or behavioural shifts that may occur in the aftermath of a disaster (e.g., large scale population movements). These scenarios are generated in a consistent manner to assess the consequences of the alternatives defined in step (2).

Fourthly, the consequences are tailored to fulfil the decision-makers' information needs, which are expressed in terms of a set of attributes (e.g., resource needs, benefit, costs, needed preparation time). In this manner, it becomes possible to rank and prioritize (counter-)measures via multi-criteria *decision* models. Additionally, MCDA techniques are a tool to facilitate discussion and consensus building by making varying objectives and the impact of changing preferences transparent (Geldermann et al., 2009). In this manner, trade-offs between the potential risk for the population and financial losses can be made. To take into account the uncertainty, which is expressed in a set of scenarios, another MCDA-step to assess the robustness of each strategy is performed (Comes, Hiete and Schultmann, 2013).

The scenarios, simulation models and methods of decision support like MCDA will be integrated into a holistic decision support framework, addressing decision makers from FSC-actors and EMAs, which are in charge in case of FSC-disruptions. The framework will allow the simulation of different crisis scenarios while experimenting with various counter measures of FSC actors or EMAs, e.g. different network configurations.

CONCLUSIONS AND FUTURE RESEARCH

While most methods contained in the described approach have already been solely applied in the areas of risk management or crisis management, some of them haven't been applied in FSC and there is no existing approach, which integrates the described methods into a holistic decision support framework, which addresses FSC-actors as well as EMAs. The main contribution of this paper is an approach that facilitates decisions and planning to make FSC more robust to hazards by combining FSC-simulations, scenario technique and multi-criteria evaluation of alternative risk mitigation measures.

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