Industrial resilience in automotive supply networks – A case study of product recalls

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Abstract

While there is substantial research about consequences of supply chain complexity on disruption risks, little research focused on the root causes of product recalls. Recall rates in the automotive industry have seen a severe increase in recent years. This research addresses the relations between supply chain design and product recalls in the automotive industry from a product-, process and location perspective. The results of this study suggest that higher supply chain complexity contributes to increasing recall rates. A mitigation approach consisting of multiple action fields is provided, tackling recalls arising from increasingly deep, broad and dispersed supply chains.

Keywords: Supply Chain Design, Decision-making, information processing

Introduction

Product recalls in the automotive industry have seen a severe increase within the last decades. This trend is observable for different markets. Analysis of data from the National Highway Traffic Safety Administration (NHTSA) and the Driver and Vehicle Standards Agency (DVSA) shows evidence that increasing recall incidents are not a national phenomenon, but an international development that affects the whole industry (DVSA, 2019; NHTSA, 2019).

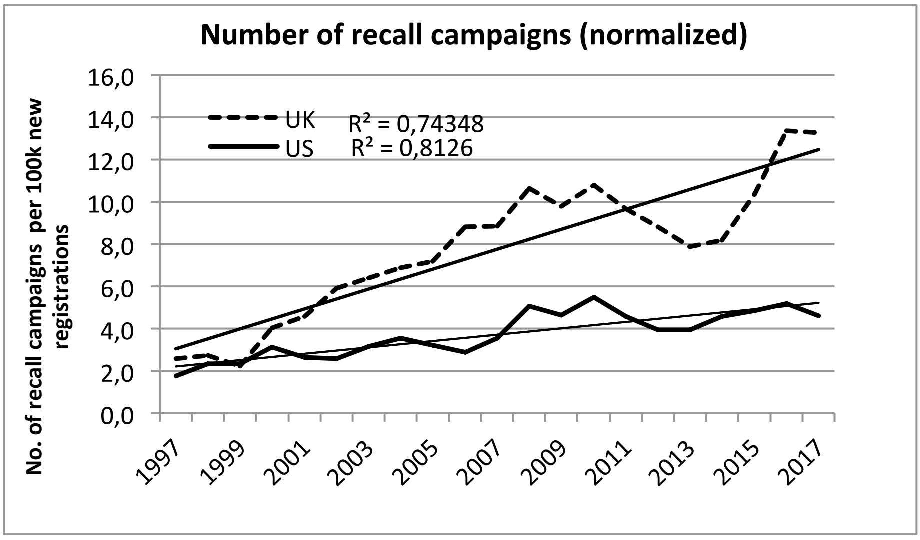

Figure 1 – Number of recall campaigns in the USA and UK (normalized)

The Takata airbag scandal further showed the reputational and financial damage that OEM and suppliers faced because of malfunctioning products. The malfunctioning airbags from the supplier Takata led to unintended ruptures, which caused at least 16 deaths and over 100 injuries (Bomey, 2017). Moreover, the product malfunction resulted in a recall of over 100 million inflators and over 42 million cars until the end of 2017 ("ADAC," 2018). Although the effects of recalls are discussed in multiple facets, such as the effects on shareholder wealth or future product reliability, there is limited understanding of the underlying causes concerning the vulnerability of manufacturer's supply networks (Kalaignanam et al., 2012; Ni et al., 2016).

Supply chain complexity

(Lyles et al., 2008) conceptualized the role of supply chains in China's product recall problems and highlighted the challenges of supply chain depth and complexity in a globalized industrial environment. Deep supply chains are characterized by a large number of subsequent upstream tier stages. In this context, traceability refers to the obligation for a documentation that proves that the supplier has followed the instructions previously agreed upon throughout the entire process chain from origin to point of sale. In deep supply chains, it is often difficult to provide a sufficient traceability of the products (Marucheck et al., 2011; Tse & Tan, 2012). Reduced traceability can cause issues such as poor supplier material, product contamination or non-conformance incoming inspections that lead to compromised quality (Marucheck et al., 2011; Tse & Tan, 2012). Accordingly, among the most frequently mentioned risks in supply chain processes are more complex supply chains (Bode & Wagner, 2015; Lyles et al., 2008; Marucheck et al., 2011; Sheffi & Rice, 2005; Speier et al., 2011). Bode & Wagner conceptualized supply chain complexity as vertical, horizontal and spatial complexity, which refers to the number of upstream tier stages, the number of tiers on one stage, and the geographic dispersion of the supply chain. It was found that increased supply chain complexity increases the risk for disruptions. The causes of these disruptions in deep supply chains are rooted in an unforeseeable interaction of small failures in the upstream supply chain, which can cause disruptions downstream (Bode & Wagner, 2015). It was not further elaborated what causes these failures and more precisely, how product, process and location based attributes foster the complexity of supply chains. Furthermore, the relations between product modularity and the fragmentation of value adding processes are yet partly unexplored. (Novak & Eppinger, 2001) examined, how product complexity influences sourcing decisions, but made a major simplification for sourcing as being a binary variable (make or buy). Hence, it was not assessed how product architecture and complexity influence the supply chain depth and breadth. Therefore, this research bridges the gap between the findings of Wagner & Bode (2015) and Novak & Eppinger (2001) by examining how product architecture influences supply chain complexity and how this complexity relates to product recalls. Moreover, prior research identified proximity of first tier suppliers in production networks as essential to ensure design compatibility and avoid lack-of-fit risks by reinforcing inter-firm knowledge exchanges (Bode & Wagner, 2015; Frigant & Layan, 2009). Accordingly, following prior research about the geographic re-configuration of automotive supply networks, geographic supply chain dispersion is examined as a further contributor to recalls (Sturgeon et al., 2008).

The findings of this research were used to create a decision support framework for supply chain design to mitigate recall related risks. The research aims to answer the following research questions:

1. How do product-, process- and location related supply network design decisions of a firm affect its product recall rate?
2. How can product recall related vulnerabilities in these networks be effectively mitigated?

To systematically capture the characteristics relevant for supply chain decision-making, an academic framework was developed. The domains capture product, process and location related supply chain characteristics. These are defined by the characteristics of the component to be bought, the processes involved in producing this component, and the location where the component is to be bought as well as the location of the end product to be sold. The decision areas following from these characteristics are shown in the framework. The result of the supply chain decision-making process is the supply chain complexity. The complexity can relate to spatial complexity, which describes the spatial dispersion of the supply chain, and the vertical and horizontal complexity, representing the depth and breadth of the supply chain.

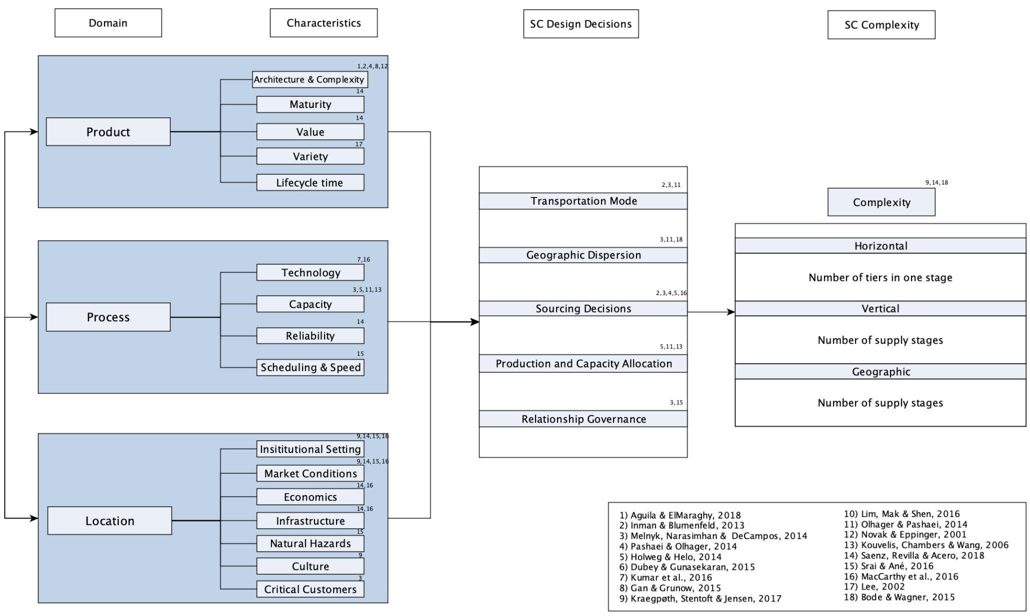

Figure 2 – Supply chain design framework

Method

This research relies on empirical data. This is due to the limited understanding of the relationship of supply network design decisions and resulting risks. A qualitative research approach was chosen, as the research questions to be investigated suggest an exploratory nature of the phenomenon (Yin, 2014). Hence, case study research was chosen to accommodate for the exploratory nature of the research questions.

Data collection

Semi-structured interviews were chosen to allow for enough flexibility during the interview process (Yin, 2014). The interviews were conducted with OEM and suppliers in the automotive sector. The questionnaire was handed to the interviewees prior to the interview to allow for preparation. In total 12 company representatives were interviewed The units of analysis in this case study were supply chain design strategies. Multiple companies and accordingly multiple units were analysed, hence the case study design followed an "embedded" approach (Yin, 2014). Moreover, the focus in these companies was set on the Supply Chain, Purchasing and Quality Management departments in Europe and the USA in order to ensure that the data obtained in the case study was received from sources, which are familiar with the topic and relate to the markets of reference in the data analysis. Interviewing different departments involved in the supplier selection process allowed to identify differences in priorities with respect to selection criteria. Within the study, 24 purchased components used for the assembly in cars were analysed according to their product architecture, their supply chain breadth and supply chain depth. Information about supply chain design were matched with the framework to identify sources of network vulnerabilities that increase the recall risk. The list of participants is shown below:

Interviewee list

Nr.	Type of Industry	Vertical Position Supply Chain	Size	Type of Product	Position Interviewee
IP 1	Automotive	OEM	> 100 bil. US$	Automobiles: engine components, finished goods	Senior Manager Supply Chain & Production Management
IP 2	Automotive	OEM	> 100 bil. US$	Automobiles	Risk Manager Supplier Selection
IP 3	Automotive	OEM	<100 bil. US$	Automobiles: finished goods	Senior Manager Supply Chain Management (Finished Goods)
IP 4	Automotive	OEM	> 100 bil. US$	Automobiles	Head of Purchasing, Quality & Strategy
IP 5	Automotive	Tier 1 (upstream)	> 20 bil. US$	Mechanical components for automobiles	Head of Sourcing & Qualiy, Head of Requirement Management, Teamleader Escalation
IP 6	Automotive	OEM	> 100 bil. US$	Automobiles: electronic head units	Purchasing Specialist Electronic Components
IP 7	Automotive	Tier 1 (upstream)	> 20 bil. US$	Mechanical components for automobiles	Director Product Development, Platform Integration
IP 8	Automotive	OEM	> 100 bil. US$	Automobiles: exterior components	Purchasing Specialist Exterior Components
IP 9	Automotive	OEM	> 100 bil. US$	Automobiles: software	Purchasing Specialist Software
IP 10	Automotive	OEM	>100 bil. US$	Automobiles: powertrain	Head of Global Quality Management, Systems Integration Powertrain
IP 11	Automotive	OEM	> 100 bil. US$	Automobiles: software	Purchasing Specialist Software
IP 12	Automotive	OEM	> 100 bil. US$	Automobiles: software	Head of Product Development: Software

Figure 3 – List of interview participants

Analysis & results

The data gained in the collection phase was analysed using a pattern-matching method. The academic framework was used to match the feedback received from the interviewees with the characteristics, which were identified as relevant in the framework.

Interviewees	IP 1	IP 2	IP 3	IP 4	IP 5	IP 6	IP 7	IP 8	IP 9	IP 10	IP 11	IP 12
A. General Information												
A1. Assumptions made when discussing supply chain design	•	•	•	•	•	•	•	•	•	•	•	•
A2. Central Tasks in the daily business												
– Managing concurring goals in supply chains	•		•		•	•		•	•		•	
– Choice of suitable suppliers for collaboration	•	•		•	•	•	•	•	•	•	•	•
– Ensuring reliable supply of parts	•	•	•	•	•	•	•	•		•		
B. Relevant factors for supply chain design												
B1. Product characteristics												
– Cost of the component	•	•		•	•	•	•	•	•	•	•	•
– Size of the component		•		•						•		
– Lifecycle time of the component	•									•		•
– Architecture: modular / integral	•			•	•	•	•	•	•	•		
– Variety of the component: options	•	•		•	•	•						
– Maturity of the component												
B2. Process characteristics												
– Speed: replenishment cycle time and lead time	•	•	•	•	•							
– Production capacity & flexibility	•	•	•		•	•	•	•	•	•	•	
– Innovative technologies for production			•		•	•	•	•	•	•	•	•
B3. Location characteristics												
– Institutional setting		•		•	•	•	•	•	•	•	•	
– Market conditions in the country of sourcing	•	•			•							
– Economics in the country of sourcing	•					•		•				
– Transport infrastructure: availability of alternative routes		•	•		•					•		
– Educational infrastructure: skilled labor		•		•	•	•			•	•	•	•
– Natural Hazards: hurricanes / earthquakes / floods		•		•	•	•				•		
– Cultural factors: trust / ethical considerations		•		•	•	•	•					
– Critical customers												
C. Mitigation Measures												
– RFID Technology					•		•			•		
– Barcode tracking					•	•	•	•				
– Data Analytics					•	•	•	•	•	•		•
– Contractual Solutions					•	•			•	•		•
– Multi Sourcing				•	•	•		•		•		
– Additive Manufacturing								•				
– Others		•		•	•	•	•		•	•		•

Figure 4 – Interview feedback summarized

By analysing the feedback of the interview partners ("IP") regarding supply chain design decisions and the depth and breadth of supply structures of the components, which were purchased for the assembly in cars, patterns regarding decision-making and supply chain complexity were identified. The results of this study show several facts:

- The depth and breadth of supply chains are determined largely by the product architecture and the integration concept.
- Cost pressure significantly extends supply chains towards deeper structures (IP 5…8,10)
- Sub-components for many products are negotiated, cost pressure affects the content of components (IP 5…8,10,)
- Increased supply chain breadth and depth increases recall risks by worsening supply chain visibility, fragmenting value adding processes and increasing lack-of-fit risk
- The results suggest that geographic complexity is associated with stronger communication barriers and a higher lack-of-fit risk

Discussion

Prior studies have suggested increased supply chain complexity as a source of risk for disruptions (Bode & Wagner, 2015; Marucheck et al., 2011; Tse & Tan, 2012). The findings of the case study confirm that supply chain complexity increases disruptions and the scope is further narrowed down on automotive product recalls. In addition, a causal perspective on failures extends the predominantly logistical contemplation of failure sources. During the case study, evidence for the relation between product architecture and supply chain complexity was collected.

Supply chain breadth & supply chain depth

Modular sub-systems such as oil or fuel pumps, electrical engines and electronics components have significantly broader and deeper supply chains than simpler, in most cases integral components. A great part of the integration efforts to create these subsystems is distributed among lower tiers (IP 2,5…8,10). Especially electronics components such as those for navigation systems, circuit boards and control units are so complex in nature, that most interviewees were not able to name the exact breadth and depth of the component, but indicated that it is very high (IP 2,6,7,10). It was found that supply chains become deeper and broader, the more electronic and electro-mechanical content is required, as confirmed by interview partners 2,5…8,10). This is due to a requirement for specialisation regarding development competences and technologies. Accordingly, requirements for competences in different technological fields lead to a fragmentation of supply structures. In contrast, supply chains become less complex when a large part of the value added can be generated with a single or several related technologies. This finding is somewhat contrary to the implications of (Novak & Eppinger, 2001) on product complexity and make-or-buy decisions. Whereas (Novak & Eppinger, 2001) found that increasing product complexity enhances in-house production, this research suggests that specialization of production and development capabilities lead to a more fragmented organization of supply and increases the breadth and depth of supply chains. Reasons for this discrepancy may be rooted in the change of product characteristics due to a higher degree of automization and electrification in cars and accordingly increased content of mechatronic, electronic and software units within the last two decades. Moreover, cost pressure was found to have an impact on the supply chain depth, but also on the content specification on lower tier levels (IP 5,7,8,10). More precisely, cost pressure encourages lower tiers to outsource their activities (IP 5…8) and determines the quality of sub components in the main component (IP 7,8). For components such as electronic control units, the sub-content is part of the negotiations and cost pressure reduces the quality of the end product (IP 7,8,10). The interviewees who were asked about the relation between supply chain complexity and recalls, confirmed that modular, often more complex products carry a higher inherent risk for malfunctions (IP 5,6,8,10). Reasons for higher failure probabilities for components with deep and broad supply chains were partly mentioned in prior literature. Worsened traceability in deep supply chain structures was identified as a source of risk for reduced quality (Marucheck et al., 2011; Tse & Tan, 2011). Multiple interview partners confirmed that traceability in general is guaranteed, but that informative value is lost when components cross firm boundaries (IP 2,5,7,10). Hence, supply chain depth is associated with worsened traceability. In addition, it was found that components that require particularly demanding manufacturing processes have a higher failure probability. For example, sub components that require particular manufacturing processes, like sintering, are more vulnerable for malfunctions, if the supplier is missing the know-how for specific steps, like the pressing or hardening of the part or if several difficult processing steps are done by different suppliers. This is why for certain components with high-tech production requirements, the failure probability is higher than for those with more basic requirements. More modular and complex components that have a high number of these critical parts are therefore more vulnerable for malfunctions.

Geographic dispersion
Multiple interview partners confirmed that product recalls in the automotive industry have its root causes mainly in design and layout failures (IP 5,8,10). Interview partner 10 is head of quality management and confirmed that approximately 80% of all recalls are due to design and layout flaws, whereas flaws in production and logistics cause the remaining 20% of the recalls. This implies that product design and development is the dominant contributor to product malfunctions and the identification and mitigation of root causes for lack-of-fit risks is highly relevant for product safety. (Marucheck et al., 2011) argued that increasing globalization in production networks reduces the traceability of components in the supply chain and therefore makes maintenance of product safety more difficult. The results of the case study confirm this argument. Multiple interview partners confirmed the importance of collaboration of design and development departments between OEM and first tier suppliers to ensure the compatibility of components (IP 5,7,8,10). The results of the case study confirm this argument. Multiple interview partners confirmed the importance of collaboration of design and development departments between OEM and first tier suppliers to ensure the compatibility of components (IP 5,7,8,10). This collaboration is compromised by spatial distance. Interview partners 8 and 10 highlighted problems with collaboration between OEM and FTS in cases where the FTS is located in rural areas, as direct communication for project based work is aggravated. Furthermore, language barriers in cases of collaboration with foreign partners make communication for joint development and design tasks more difficult (IP 6,8). This implies that more local collaboration in development may be a solution to reduce design flaws. However, an ongoing specialization process, technological constraints for production and strategic cost based considerations suggest that there is rather a trend towards more dispersed supply structures than towards local structures (IP 1,2,5…8,10). Multiple interview partners confirmed that competence for different key technologies are located in different regions of the world (IP 1,2,4,5…11). Therefore it seems unlikely that network structures will become less dispersed in the future.

Mitigation strategies
The case study revealed multiple action fields. Multiple research scholars highlighted the importance of traceability as an effective countermeasure to tackle issues such as poor supplier material, product contamination or non-conformance incoming inspections that lead to compromised quality (Lyles et al., 2008; Marucheck et al., 2011; Tse & Tan, 2012). As many interview partners pointed out, there is a trade-off between traceability costs and benefits, which determines the degree of the granularity of the data (IP5…8,10). RFID technology can improve data granularity, as it enables the traceability of the component within the production and assembly process. However, the associated costs for tracking and capturing field data from components that are used in cars in large numbers, which can easily reach several millions in case of car models that are sold in large quantities, imposes a significant cost factor for car manufacturers. It is questionable if a broad field data collection would be financially beneficial. Hence, an approach, which selectively collects data from a limited number of sold models would be more suitable (IP 7,10).

Production processes were identified as another field of high relevance for traceability (IP 1, 5…8,10). The interconnection of data flows across firm boundaries allows to capture important variables in all steps of the production process and to link the data of all steps to use it for the end product (IP 5,8,10). This interconnection enables the monitoring of process variables and a faster reaction in case of defective production (IP 5…7,10). Moreover, root causes for product malfunctions can be detected more easily (IP 5,10). However, higher costs associated with the gathering and management of the data limits the applicability of production traceability. Accordingly, this requires an empirical evaluation of product categories and the scope of production traceability efforts should be focused on products and components with an empirically verified high failure probability (IP 6).

(MacDuffie & Fujimoto, 2010) anticipated the loss of control that automobile manufacturers will suffer due to products with a higher degree of digitization. However, they argued that older car manufacturers ("dinosaurs") will be able to manage greater product complexity in their supply chain due to their legacy better than younger companies. The results of this work suggest, however, that it is precisely this legacy that complicates the organizational learning of major manufacturers, thereby causing inertia in processes that compromise product safety. In order to establish minimum standards for software quality, legally binding conditions for tests should be defined for each safety relevant software component. In addition, several interviewees have argued that government authorities should consider a disclosure requirement for safety relevant software (IP 10,12).

Conclusion

As the first study to link product-, process and location characteristics with product recall rates, the findings of this study are highly relevant considering increasing product recall rates in the automotive industry. Prior literature identified trends towards a reconfiguration of supply networks in the automotive industry (Sturgeon et al., 2008). The results of this study suggest that the dispersion of supply networks is associated with higher recall rates as the compatibility of components is put at risks and collaboration is aggravated. The study further identified product complexity as a driver for product recall rates, as it fosters supply chain complexity and aggravates traceability. Cost pressure and capacity constraints exacerbate the supply chain complexity as outsourcing activities increase. In order to mitigate the consequences of increasing supply chain complexity, this research suggests the implementation of new technologies to increase the traceability of production and logistics processes. Data connectivity and production organization as well as new testing methods improve the product compliance and traceability along the supply chain. Moreover, the results reveal that the complexity of digital products require new ways of product testing and furthermore necessitate a re-assessment of governmental regulations regarding the disclosure and testing procedures

Implications and Contribution

By classifying supply chain design into three domains and matching the literature with empirical data, this study is the first to demonstrate how product-, process- and location based characteristics shape the complexity of supply chains. Furthermore, this study reveals new relations between product architecture and supply chain complexity that challenge findings of existing research regarding make-or-buy decisions. While prior research argued that product complexity fosters make-decisions, this research finds that higher product complexity leads to a fragmentation of value-adding processes and accordingly to deeper and broader supply chains. It was shown that the complexity of products has various effects on failure probabilities. Electronics, electro-mechanical components and software components are associated with a high number of sub-entities and functional interrelations within the components. At the same time, these components become increasingly important for modern cars. Hence, automobiles are expected to become more complex in the future.

To tackle problems associated with a higher product complexity, this research suggests a policy mix consisting of multiple fields of action for the implementation of mitigation strategies in practice. Accordingly, reducing recalls effectively is not straightforward, but requires actions in different fields regarding logistics, production and regulation. As technology in fields like autonomous driving is rapidly proceeding, the responsibility of car manufacturers to provide safe products despite increasing complexity gains an even greater importance. The results of this study show evidence that software related recalls are not an emerging issue for manufacturers, but already represent a significant fraction of recalls leading to potentially severe financial and human costs and are expected to increase further rapidly. This poses an urgent need for standardization of processes and regulations regarding the testing of new software. Inertia caused by the legacy of car companies has to be overcome quickly to cope with the transformation of the automobile from a purely mechanical to a highly digitized transport medium.

Limitations & further research

As with all studies, this research is subject to limitations and therefore provides possibilities for further research. Although several fields of actions have been identified by this study, further research should focus on implementation strategies with the aim to improve implementation strategies regarding data connectivity in supply chains and operations. Moreover, it should be specified, in which order the countermeasures should be implemented and if they should start upstream or downstream in the supply chain. Lastly, it should be mentioned that product recalls have only limited significance as a measure of product quality. Even though product recalls went up significantly within the last decades, there is little doubt that vehicles became significantly safer during this time. Hence, with new safety features there are more possibilities for malfunctions. This development certainly contributes to higher recall rates and puts the results in perspective. Nevertheless, we are convinced that this research provides valuable insights for theory and practice.

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