# The Link Between Supply Chain Design Decision-Making and Supply Chain Complexity

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## An embedded case study

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**Abstract**. This paper presents a conceptual model of the supply chain characteristics leading to supply chain complexity. This is combined with the change complexity of supply chain improvements, to reflect the complexity found in supply chain design decision-making when improving global supply chains. These two dimensions are used empirically, in the investigation of eight embedded cases of supply chain re-design, in a global OEM. Three contributions are made, improving the understanding of the link between supply chain design decision-making and supply chain complexity. First, the impact of different types of supply chain complexity on decision-making. Detail complexity leads to a higher need for resources for data collection and analysis, while dynamic complexity leads to challenges in predicting future performance. Second, the degree of change complexity is determining the potential supply chain complexity reduction. Third, a systematic bias resulting from low transparency on the marginal impact of increasing or decreasing supply chain complexity is proposed to lead to increasing supply chain complexity.

**Keywords:** Global supply chains, Supply Chain Design, Supply Chain Complexity

## 1 Introduction

Supply chain design decisions are characterised by complexity [1][2], which is further complicated by the environment becoming increasingly turbulent [3]. For these reasons, the post assessment of supply chain design changes often reveals "hidden cost" and unexpected complexities, challenging the foundation of realized supply chain design changes [4]. In addition, high supply chain complexity is associated with negative performance impact [1]. Implying that companies must either continuously work towards reducing supply chain complexity, or equip themselves to cope within this new context. A step towards being able to do any of these two is to understand how supply chain design decisions are linked to supply chain complexity and vice versa. The objective of this paper is to conceptually model complexity related to supply chain design, and based on this conceptual model, empirically investigate the link with decision making.

The paper is structured as follows. First, the parameters related to the complexity of the supply chain and supply chain design changes are proposed. Second, the two complexity dimensions are applied for eight embedded cases to explore the interplay between decision-making and complexity.

## 2 Conceptual framework for assessing decision complexity

### 2.1 Supply Chain Complexity

The parameters leading to supply chain complexity can be classified into detail and dynamic complexity. Detailed complexity is related to the number of variables which needs to be managed, while dynamic complexity is related to the dynamism, interdependence and causal ambiguity of the variables [5][6]. In a supply chain context, these parameters have been decomposed into three areas, upstream complexity, internal manufacturing network complexity, and downstream complexity, mirroring a supply chain.

For the upstream supply chain, seven parameters driving complexity is suggested. First is the *number of suppliers*, which needs to be managed. This leads to detail complexity as the number suppliers is linked with the needed resources for managing these [6]. The *delivery lead time* and *delivery reliability* (timing and quantity) are the second and third parameter, respectively. A long delivery lead time requires the supply chain to plan details on a longer horizon, increasing the detail complexity. In addition, the reliability of these deliveries is a driver for dynamic complexity, as uncertainties need to be managed [6]. The fourth parameter is the *raw material price uncertainty*, fluctuating prices creates dynamic complexity which need to be managed to avoid loss of competitiveness from price arbitrage [8]. The fifth parameter is *upstream capacity constraints*, as the focal company has to manage its bottlenecks throughout the supply chain to avoid shortages or high inventory levels. Therefore, the number of bottlenecks is a driver for detail complexity [7]. The sixth parameter is the *governance mode of the supply chain*. Five governance modes; market, modular, relational, captive and lead firm are used [9]. These five represent a gradual increase in supply chain complexity, related to detail complexity. With the argument that a fully integrated supply chain will have more details to manage than one which is primarily driven by arm’s length relationships (market). The seventh and last parameter is the *extent of global sourcing*, which leads to detail and dynamic complexity as volatility of exchange rates, tariffs, transport costs all impact the competitiveness of the supply chain [3].

Building on extant literature six parameters are expected to have an impact on internal manufacturing network complexity. The first parameter is the *depth and width of the bill-of-material (BOM)*, which lead to detail complexity, as more items need to be managed [6]. The second parameter is the *type of manufacturing process*; here a continuum from one-off customized products to a repetitive flow of similar products can be identified [7]. The further towards the one-off customized products, the higher the complexity, as multiple new items needs to be managed, leading to high detail complexity [6]. The third parameter is *internal capacity constraints*; here, the number of bottlenecks found in the manufacturing networks adds to the detailed complexity, as bottlenecks needs to be managed for planning purposes [7]. The fourth parameter is related to the *stability of the production schedule*, which if low causes dynamic complexity [7], as it creates a production environment which has to account for the unreliability of the production plan. The fifth parameter is related to the network aspect, namely the *extent of global production*. For global operations, supply chain complexity will be high, due to detail complexity from the numerous production locations and dynamic complexity from product allocation decisions, local labor agreements, tariffs, and trade agreements, which change over time [3] as well as interdependencies in planning, physical goods and information flows. The sixth and last parameter is *the maturity of the product design and processes*. If the product design is mature, fewer changes will occur, hence reducing the dynamic complexity. If the processes are mature, the uncertainty associated with the execution and planning of process activities is reduced, limiting dynamic complexity.

The downstream supply chain is divided into five parameters leading to complexity. The first being *demand variability* [6], here a high demand variability leads to high dynamic complexity, as it becomes complex to orchestrate the internal manufacturing network and upstream supply chain [8]. The second parameter is the *number of sales customers*, which is a driver for detail complexity, as the number drives the need for management efforts [6]. The third parameter is the *heterogeneity of the customer needs*, which lead to both detail and dynamic complexity as low heterogeneity both means more unique requirements to manage, as well as variability in the required deliveries [6]. The fourth parameter is the *length of the product life cycle*, a long product life cycle results in low complexity, while a short life cycle results in high complexity through a frequent change of products, as well as additional details needs to be managed as new and old products co-exists [6]. The *extent of global sale* is the fifth and last parameter. Similarly to the extent of global production, this leads to detail and dynamic complexity, as tariffs, exchange rates, transport costs all have an influence on the network [3].

In addition to these, the *level of interdependence* is a key driver of complexity across the entire supply network. If a supply network is primarily defined by pooled interdependence, a shift in supplier is likely to be simple. While if the interdependence is sequential or even reciprocal, the decision in the supply network is interconnected, and a change in one area might infer changes in multiple interconnected areas [10].

### **2.2** Supply Chain Change complexity

Change to the supply chain design inherently contributes to the complexity faced by decision-makers. Changes to the supply chain reflect decision within upstream-, internal manufacturing network-, and downstream changes, similar to source, make and deliver in the SCOR framework.

*Upstream changes* to the sourcing setup can be simple, such as finding a new supplier in an already known location, or more complex if it is in an unknown offshore location. Of the highest complexity is changing ownership of the production of a component (either outsourcing or insourcing).

For *internal manufacturing network changes*, four possibilities for change are suggested. At the simplest, changes can be made to the production network by shifting to production in a known location of close proximity (onshore insourcing). Outsourcing production to a known location of close proximity (onshore outsourcing) or internally owned production in an offshore location (captive offshoring) represent higher levels of change complexity. The most complex change is to outsource production to an unknown offshore location (offshore outsourcing) [2].

For *downstream changes***,** distribution channels and the setup of warehouses are relevant dimensions. Here, a change can be a new distribution channel in a known location as the simplest, more complex if it is in a new location, while a change of ownership of the distribution channel is seen as the most complex. Changes can occur in multiple dimensions simultaneously, making the resulting change complexity higher.

### 2.3 Complexity framework

Combining the two dimension, then supply chain complexity and change complexity represents two areas of complexity; the complexity of the entity being changed, and the complexity of the proposed changes, as illustrated in figure 1.

## 3 Method

The paper builds on an explorative case study to investigate how supply chain design decisions are linked to supply chain complexity. The case study approach is ideal for in-depth investigation of how supply chain design decisions are influenced by and influences supply chain complexity [11]. To be able to both generalize findings and achieve in-depth understanding [12], an embedded case study approach is chosen. Here, the focus is on eight different supply chain improvement projects undertaken in a global industry leading OEM. The cases have been chosen to investigate a mix of high and low supply chain- and change complexity.

Each case has been followed in their total duration from ideation to implementation decision, and if applicable, implementation. Thus, the duration of the cases ranged from three months to three years. The longitudinal data enabled an investigation of both the ex-ante intended outcome and the ex-post achieved outcome, as well as rich data on the impact of decision-making, change complexity and supply chain complexity. To ensure an unbiased understanding of the relationship with complexity in supply chain design decision-making cases, both cases which did and did not implement the proposed changes, were investigated. For each case, the researchers together with involved supply chain managers mapped the supply chain complexity and the area of change complexity, by scoring each dimension based on perceptual measures. The supply chain complexity was mapped for the subset of the OEM's supply chain relevant for the supply chain design project. Further, the objective for each supply chain design project was mapped, together with the decision process and outcome. Results from the eight cases of redesigning the supply chain are summarized in Table 1.

**Table 1.** Overview of supply chain design cases.

| Case | Supply chain change complexity | Stated objective | Decision Process | Realized Outcome |
|---|---|---|---|---|
| A | Outsourcing of internally produced composite product. Utilizing suppliers of the shelf-available technology. | – Cost reduction<br>– Improve technical control<br>– Complexity reduction | **Implemented.** Decision based on direct cost savings. | Upstream-, internal manufacturing network- and downstream complexity reduced. |
| B | Outsourcing of wire production. Divesting of production equipment. | – Cost reduction<br>– Avoid investments in production equipment<br>– Reduce complexity in factory and upstream supply chain | **Implemented.** Decision based on direct cost savings. | Internal manufacturing complexity reduced from outsourcing. |
| C | Outsourcing of assembly and design of auxiliary module. | – Complexity reduction<br>– Utilizing supplier development capabilities | **Not implemented.** Decision based on direct cost comparison. | Not implemented |
| D | Introduction of second source. | – Cost reduction<br>– Increased supply network reliability | **Implemented.** Decision based on cost reduction and increased network reliability. | Increased planning complexity from operating with two suppliers. |
| E | Outsourcing of machining activity. | – Cost reduction<br>– Complexity reduction from simplifying supply base and internal manufacturing setup. | **Implemented**. Decision based on direct cost savings. | Upstream and internal manufacturing network complexity reduced from outsourcing. |
| F | Offshoring of controller module. | – Cost reduction | **Implemented.** Decision based on direct cost savings. | Increase in detail complexity from managing additional Chinese supply base and assembly location. |
| G | Shift to kit-delivery of brake-system and outsourcing of design. | – Cost reduction<br>– Complexity reduction from utilizing suppliers of the shelf concepts | **Not implemented.** Decision based on direct cost comparison. | Not implemented |
| H | Offshore and outsourcing of module assembly. | – Cost reduction from establishing production close to emerging markets. | **Implemented.** Decision based on direct cost savings. | Increased planning complexity from managing inbound supply chain for outsourcing partner. |

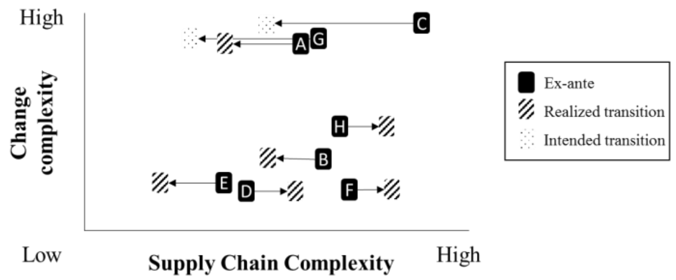


**Fig. 1.** Case Mapping: Intended and realized transition.

Further, for each case, the impact of the supply chain design change on the supply chain complexity was mapped. For cases where the design change was implemented, the impact was mapped. For those cases, where it was decided not to implement the proposed changes, the impact of the intended changes to supply chain complexity was predicted based on the impact to the dimensions of upstream, internal manufacturing network, and downstream complexity. This enabled a mapping of the realized or intended transition for each case based on aggregate measures of supply chain complexity and change complexity as shown in Figure 1.

# 4 Case discussion

## 4.1 The impact of change complexity and supply chain complexity.

High supply chain complexity was associated with significant resources spent on estimating the impact of the proposed decisions. This is ascribed to the complex interactions and unclear causality due to complex interdependencies (Case F, G and H). Thereby supporting that supply chain complexity lead to negative consequences in the form of additional resources required for managing and improving the supply chain [1]. An higher level of supply chain complexity is, thus, associated with higher resource requirements for justifying a decision. In addition, it was found that detail complexity was associated with a higher need for collecting, preparing and analyzing more of the same data (Case B and F), while dynamic complexity was associated with difficulty in problem understanding, and predicting impact across multiple tiers (Case A, C and G). Change complexity was associated with resources required for developing and validating the new supply chain design, such as transport solutions, logistics processes, production processes, and even adjusting product requirements and designs. The extent of change to existing design variables required the focal company to allocate resources with technical competence and strong functional understanding (Case A, C and G). The cases further suggest a significant interaction between change complexity and decision complexity. When change complexity was high, it increased decision-making complexity by expanding the number of design solutions, which needed to be evaluated, each with different impacts and causality (Case C and G).

## 4.2 Supply chain redesign to reduce complexity.

The objective of reducing supply chain complexity was highlighted in a number of redesign projects (Case A, B, C, E and G). In general, these were experiencing medium or high level of supply chain complexity, suggesting that redesign initiatives were a response to increasing levels of supply chain complexity. Further, the higher the change complexity, the higher was the intended or realized reduction in complexity. Hence, working with multiple dimensions simultaneously, enables a larger potential for reducing supply chain complexity (Case A, G, and C). For instance in case A, where a combination of outsourcing production processes and utilizing suppliers' of-the-shelf technology, significantly reduced supply chain complexity. This was achieved by reducing number of items and suppliers maintained, eliminating internal capacity bottlenecks, adding access to global production locations and distribution capabilities, and shifting to market relations. Contrary, initiatives relying on changes within a single dimension provided smaller complexity reduction potentials (Case B and E).

**4.3** Impact of decision-making on supply chain complexity.

Trade-offs between supply chain complexity and strategic benefits [6] was a visible part of the decision-making considered in the majority of the cases. During scoping and discussion of project initiatives, reduction of complexity was central together with alternative performance improvements, such as cost reduction. However, during decision-making meetings, primary attention was focused on what could be quantified with immediate impact on the OEM's profit/loss statement and validated by finance. Which meant that financial assessments did not account for the added complexity imposed on the supply chain, since the marginal impact of this could not be quantified using standard cost accounting principles. This leads to the proposition that increasing supply chain complexity, rests on the limited visibility of the marginal impact of supply chain complexity during managerial decision-making. Several mechanisms and case findings explain and support this. First, different levels of transparency and confidence in outcome are prevailing when discussing supply chain complexity in a trade-off with other strategic benefits. For instance, a ten percent price reduction from utilizing an offshore supplier is more tangible than the detrimental performance impact of longer and unstable lead-times. All cases revealed this discrepancy in transparency, suggesting supply chain complexity is prone to increase unless carefully considered during decision-making. Initiatives aimed at reducing supply chain complexity are not justified based on the benefits stemming from that reduction, due to low transparency on the marginal performance impact from reducing supply chain complexity (Case C and G). Rather, such initiatives are subject to the complexity reduction being supplemented by more tangible performance improvements (Case A, B and E), such as direct cost reductions. Second, initiatives seeking to improve aspect of the supply chain, typically factor inputs such as labor or material costs, are not adequately penalized for increases in supply chain complexity (Case D, F and H). This leads to a systematic increase in complexity, while the ability of decision-makers to reduce complexity is constrained.

## 5 Conclusion

By exploring the combined roles of supply chain complexity and change complexity, advances are made to the understanding of complexity and its impact on supply chain design decision-making. First, by presenting and testing a method for assessing supply chain complexity and change complexity, it enables an understanding of the role of complexity on supply chain design decision-making. Second, the findings document the negative effects of high supply chain complexity, through reduced decision speed and potential erroneous decision-making. In particular, the paper shows how high levels of detail complexity can be associated with the amount of data required for decision-making, meanwhile, dynamic complexity relates to the difficulty of estimating causality. In addition, the cases help explain why increasing supply chain complexity constitutes an increasing managerial challenge. It is revealed that the utilization of direct costing principles for decision-making constitutes a systematic bias underestimating or neglecting the consequences of supply chain complexity, propelling companies towards increased supply chain complexity. For practice this highlights the risk of a singular focus in supply chain design decision-making. Especially, as transforming away from high supply chain complexity becomes increasingly difficult as complexity increase.

As the study builds on an embedded case study, further research should seek to replicate and further substantiate the mechanism with which supply chain complexity is dependent on decision-making practice. In addition, research should seek to link the nature of supply chain complexity, upstream, internal, or downstream, with the aspects of change complexity. Another research proposal would be to improve the understanding of mechanisms mitigating the negative consequences of supply chain complexity in decision-making.

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