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# Developing Digital Supply Network's Visibility Towards Transparency and Predictability

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**Abstract.** Despite advances in Industry 4.0 technologies, supply chains have fallen short in enabling agile supply chain responsiveness. Conceptually, the enablers of connectivity, visibility, and transparency are well defined, yet their operationalization remains a challenge. In this paper, we analyse a successful case study in the domestic electrical machinery industry and derive from it a proposal for data integration lifecycle phases and socio-technical domains to structure the challenges that need to be overcome as a prerequisite for digital supply networks' visibility towards transparency and predictability.

**Keywords:** Digital Supply Networks, Supply Chain Management, Visibility, Transparency, Predictability, Agility.

## 1 Introduction

The COVID-19 black swan event has revealed that there is still a significant lack of connectivity and data exchange built into the fabric of global Supply Chains (SC) [1]. This puts Supply Chain Management (SCM) in the spotlight due to its limited, and also not sufficient, connectivity, visibility, and transparency capabilities [2,3] for enabling agile supply chain responsiveness in the face of disruptive events towards resilient SC operations [4,5]. A situation that in the light of Industry 4.0, and the post-COVID world, is no longer acceptable considering all available digital technologies such as the Internet of Things (IoT), End-to-End Digital Connectivity, Cloud Computing, Blockchain, and Predictive Analytics – capable of enabling superior “digital” SCM operations [6,7].

In today's digital and global world, the traditional SC model continues to evolve not only from “analogue” to “digital” to facilitate electronic data interchange between all business partners [6], but also from a supply “chain” to a supply “network” model to create flexibility in the supplier base [7]. Together, these trends enable resilient Digital Supply Networks (DSNs), capable of creating “flexibility” and “responsiveness” in SC operations through digital technologies and reimagined business processes [6,7].

In this research, we aim to address the question: How to enable three key digital capabilities of DSN: (i) visibility, (ii) transparency, and (iii) predictability to support

agile practices in their SCM? Hence, we understand visibility – as the ability to trace, monitor, and obtain relevant data through a DSN to develop sustainable strategies and enable data-driven decisions that can lead to operational efficiency, increased customer service abilities, and improved on-time response to unexpected problems [2]; transparency – goes beyond “visibility”, and entails the ability to gain insights through greater SC visibility by running data analytics to manage risks more effectively across SCs [3], and predictability – builds on “visibility” & “transparency” to create the ability to forecast possible SCM incidents before they happen to avoid or reduce their impact on SC operations [8]. Moreover, agility in SCM refers to – the ability of an SC to reconfigure dynamically and quickly as the market conditions change in response to the customer demand [9].

This paper presents a holistic analysis discussing the strategic, organisational, and technical challenges that need to be addressed as prerequisites for developing visibility, transparency, and predictability as digital capabilities in DSNs to enable agility in SCM.

This paper has been motivated out of lessons learned from consulting projects by the authors on “SCM (data) Integration”, which call for more socio-technical approaches for the aforementioned digital capabilities building.

## 2 Literature Review

Lit review serves as background review

According to the scientific and grey literature, developing “digital capabilities” such as visibility, transparency, and predictability in DSNs seems to be the most promising path towards the future of “agile” SCM [9].

As a starting point, from a strategic perspective, the literature highlights the urgency of evolving in the direction of data-driven SCM practices since these have proven to enhance the timeliness of decision-making and SC performance in terms of improved inventory levels, lower costs, and reduced risks while attempting to meet the changing customer demand [11-16]. As stated by [11], “[...] in the big data era, the decision-making of SCM must be increasingly-driven by data instead of experience”. [12] proposes a data-driven SCM decision-making framework that focuses on the four operational flows of an SC (viz.: material, information, knowledge, and time flows) to support the data requirements for adopting data-driven SCM practices. Hence, in a data-driven SC, “information is shared across the entire SC to connect SC partners and provide end-to-end SC data access to SC managers” [13,14]. Such data accessibility is being more and more understood as a critical source of value creation and competitive advantage [15] since data enables SC managers to gain greater “visibility” of their SC operations to identify trends in costs and performance, support process and planning control, capacity and inventory monitoring, and production optimization [14-16]. Therefore, data-driven SCs are leading to new SCM frontiers by focusing on the development of visibility, transparency, and predictability through digital capabilities in SC operations [14].

Next, from an organisational perspective, the literature remarks that the successful adoption of data-driven SCM practices needs to be supported by its respective data-driven decision-making culture [17-20]. In this context, a data-driven culture can be

defined as the extent to which SC managers make decisions based on insights extracted from (end-to-end) SC data [18]. Developing a data-driven SCM culture requires SC partners to share their data to realize data-driven SCM capabilities and that SC managers base their decisions on data, rather than their instinct [19,20]. This brings SC managers to the centre of the discussion when it comes to “transparency”, in addition to “visibility”. Transparent data-driven systems are crucial for building trust among SC partners for all to share their data and to enable the integration and the timely availability of end-to-end SC data. This will lead to more agile and resilient SC operations. SC transparency provides SC partners with new data-driven capabilities, allowing them to know what is happening upstream in the SC and communicate the insights opportunely across the SC to improve demand forecasting and process optimization [3,21].

Lastly, from a technical perspective, the literature notes that SC partners’ data sharing and data integration capabilities intended for offering end-to-end SC data availability supporting data-driven SCM decision-making practices are a prerequisite for developing “predictability” as part of the digital capabilities of SC operations [12,22-24]. Real-time data sharing and data integration across SC partners allow for better data-driven decision-making providing all SC partners with the data they need when they needed for agile decision-making [12]. Addressing the “data sharing” and “data integration” challenge requires the adoption of interoperability standards and protocols by all SC partners aimed at the horizontal integration of their SCM systems [22,23]. The timely electronic data interchange between SC partners increases “visibility” and “transparency” among them and promotes a high level of flexibility to respond quickly to problems or failures even before these have happened by predicting them [24].

### 3 Case Study

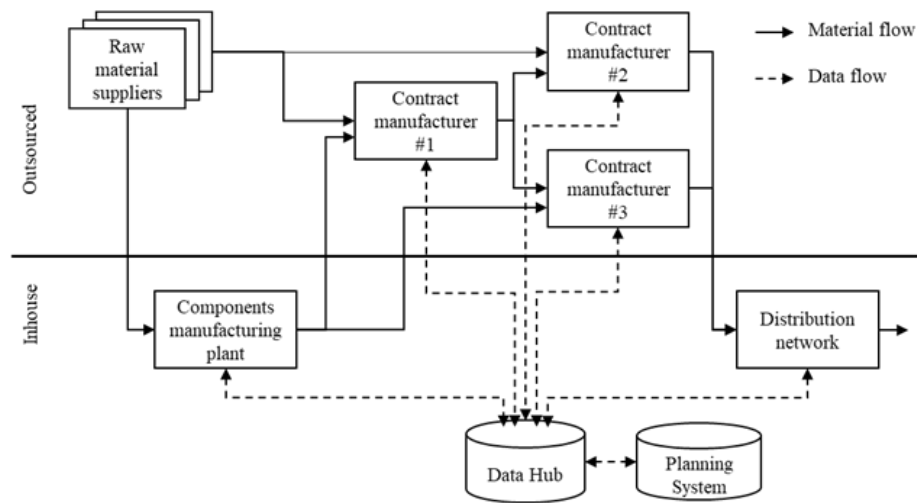
To answer our research question, we analyzed a novel case study of a manufacturer’s supply network for domestic electrical machinery. The case study’s supply network operates as follows: The highest value-adding sub-assemblies of the products, which are also the most sensitive from an intellectual property perspective, are assembled at its in-house plants. The distribution of finished products and spare parts is managed through the OEM’s network of regional distribution centers and warehouses. The OEM company uses e-commerce to sell directly to the consumer (see Fig. 1).

The case company (OEM) has outsourced a large share of its lower value-adding activities to its SC partners, hereafter referred to as Contract Manufacturers (CMs). Taking advantage of their specific capabilities, a supply network has emerged. The resulting network needs to be digitally tied to the in-house nodes of the OEM’s SC to achieve better “visibility” and “transparency” to enable the consideration of the CMs in the decision-making processes related to the demand and supply planning system.

The nature of the business is characterized by high-demand fluctuations driven by seasonality and promotional activities. Managing these fluctuations effectively requires developing “visibility” into the entire supply network. However, this is currently very limited as it is relying on the traditional means of information exchange. The usual approach of phone calls and e-mails with attachments creates latency in the information collection and delays the decision-making with the result that decisions are often

outdated before they are communicated and confirmed by the CMs. Hence, iterative negotiations between the OEM and its CMs are the norm. Furthermore, to protect their profitability, the negotiations have imposed extended frozen horizons and penalties for changes in plans, limiting the supply network agility and flexibility.

The tentative solution to manage the supply network more efficiently and nimbly was to incorporate the CMs directly into the OEM's planning system with regular, automated data interfacing to enable matching demand with supply within the SC constraints. Achieving this integration presented not just a technical challenge but also an organisational and strategic one. The emerging problem and its accompanying challenges will be discussed in the following sections.



**Fig. 1.** Case Company's Supply Network Illustrating the Complexity of Material Flows between In-house and Outsourced Operations as well as the Solution Approach

### 3.1 Challenges in Digital Supply Network Visibility Across SC Partners

With the number of CMs (SC partners) that need to be integrated to achieve end-to-end "visibility" in the OEM's supply network, the stakeholders quickly noticed that the recurring challenges across their (data) integration were not only "technical" in nature but also "organisational" and "strategic"; these have been summarized in Table 1.

During the engineering of the data integration phase, reducing the effort to establish the integration with predefined data specifications is fundamental for both, reducing the barriers to onboarding and enabling "data integration" before changes to the data source and data destination systems require modifications. The ability to access and integrate data from multiple sources into the same target system was fundamental in achieving greater supply network "visibility". However, this, in turn, required the ability to manage less than perfect data quality, because each missing data source challenged the data integration efforts. In extension, the ability to identify whether data quality issues stem from a lack of business process compliance (i.e., data not collected) or from an error in

the data extraction itself. Simplifying the unified data model to ease the harmonization of data deliveries is highly beneficial. Finally, the frequency of data exchange has to be appropriate with the often desired “real-time” data exchange, which may be appropriate for telemetric data from the shop floor but not for data-driven supply network decisions.

While pursuing the supply network (data) integration, organisational aspects played an important role too. The speed of defining or adjusting business processes and either developing or activating “user interfaces” in the target system was essential for data integration. The continuity of daily business operations had to be ensured for the switch to a supply network with increased “visibility”.

Strategic aspects always play a role during this phase of the supply network (data) integration and can be considered risk factors. Outsourcing partners generally see the lack of “visibility” of their customers into their own operations as beneficial. This led to cases where motivating and onboarding CMs to the efforts was difficult. As a compromise, not all CMs could be integrated with the same degree of visibility, for example, inventories only or inventories and manufacturing capacity. Even they were motivated, the data model’s technical specifications required negotiations around the degree of visibility into the CMs’ lower-tier supply networks or granularity of inventory status. Likewise, the decision of whether data would flow only from the CM to OEM or in both directions was a critical discussion point, because the CM could benefit from better “visibility” into the OEM’s demand signals and/or supply status to improve its operations too, promoting in this way greater supply network “transparency”.

During the daily operations phase, the main technical challenge is the time that it takes to extract data. It is crucial to ensure “timely” extraction and reduce resource consumption on the data sources which are generally the systems of record. After extracting the data, continuous data quality assurance is required to prevent poor data from entering the data destination and disrupting daily operations and predictions. The data connection itself has to be secured to prevent unauthorized access and accidental data leaks. Organisationally, the challenges shift to the supply network coordination and timely execution of activities to use the gained “visibility” and achieve “agility” in decision-making and therefore in operations. A key challenge is in turn the completeness and seamlessness of the business processes which require “coordination” across SC partners because there is no longer an option to manually intervene and mitigate gaps. Particularly, new product introductions and product end-of-life activities turned out to be particularly challenging due to their “cross-functional” nature, which requires alignments between engineering, marketing, sales, sourcing, and production functions. Strategically, the “transparency” of data visibility within and across the supply network is challenging beyond data privacy as it faces the desire of some CMs to at times keep partners partially in the dark to avoid becoming easily replaceable.

Despite requiring clarification at the data integration phase, multiple challenges only occur at the end-of-life phase which can be either a change of product portfolio or the termination of an SC relationship. Ownership of the extracted data can become a point of contention; for example, who owns the raw data extract by the OEM, who owns the processed data, if any. Proof-of-deletion may become a challenge and in addition, as an organisational challenge, means a loss of historical data and the insights hidden within. Even if the relationship ends, an SC partner may want to continue to signal its desire to

regain the relationship and switch from providing capacity data to providing capability data. That, however, is hard to define for operational purposes. Hence, an organisational challenge is the continuity of the business process(es) when switching to a different CM or even returning the physical production process in-house. Strategically, the SC partner integration can mean a shift in the balance of power if the effort to switch is so high that the supply relationship becomes sticky and causes a supplier “lock-in”. In this phase, we also need to consider changes to the business or the underlying information systems. Although there might be no change to the supply relationship or the intent on continuing with the data integration, changes to the business and business environment may require changes in the extraction data interfaces, as do changes to the data source like information system upgrades which may mean changes to the system’s data model or a new system altogether.

**Table 1.** Challenges Categorized by Domain and Data Integration Lifecycle Phases

Lifecycle Phases	Strategic Domain	Organisational Domain	Technical Domain
Engineering of Data Integration	<ul style="list-style-type: none"> <li>• Motivate CM to share data</li> <li>• Define the level of data sharing</li> <li>• Define technical specifications</li> <li>• Decide on mono- or bi-directional data exchange</li> </ul>	<ul style="list-style-type: none"> <li>• Define an agile business process</li> <li>• Develop user interfaces development or activation</li> <li>• Ensure continuity in business process execution (before &amp; after integration)</li> </ul>	<ul style="list-style-type: none"> <li>• Develop data integration logic</li> <li>• Harmonize data model</li> <li>• Access data from multiple sources &amp; merge in target system</li> <li>• Manage data quality</li> <li>• Identify missing data</li> <li>• Define frequency data exchange</li> </ul>
Daily Operations Management	<ul style="list-style-type: none"> <li>• Ensure transparency of data visibility within and across organisations</li> </ul>	<ul style="list-style-type: none"> <li>• Execute (timely) business process steps within &amp; across organisations</li> <li>• Ensure complete and seamless to-be-process</li> </ul>	<ul style="list-style-type: none"> <li>• Extract, transfer and process data efficiently</li> <li>• Monitor and control continuous data quality</li> <li>• Secure data connection to authorized source(s)</li> </ul>
End-of-Life Management	<ul style="list-style-type: none"> <li>• Limit relationship stickiness due to the sunk cost of integration</li> </ul>	<ul style="list-style-type: none"> <li>• A switch contract manufacturer (supplier) or re-integration to in-house supply network</li> <li>• Disconnect without loss of business (data) history</li> </ul>	<ul style="list-style-type: none"> <li>• Clarify data ownership and retention of data</li> <li>• Switch exchange from production capacities to capabilities</li> <li>• Re-adjust business process and interface</li> </ul>

### 3.2 Discussion on Possible Solution Directions

The objective of SC partners’ data sharing and data integration efforts is to gain “visibility” across the company supply network for data-driven and agile decision-



making. From initial assumptions, the only expected challenges are of a technical nature and can be easily overcome. To answer the research question of enabling “visibility” and “agility” of DSNs operationally, the case study showed a nuanced picture of various challenges occurring. These challenges vary across the lifecycle phase of data integration (see Table 1) and were rooted not just in the technical domain but also in the organisational and strategic ones, as would be expected by a socio-physical system.

These challenges were successfully addressed with an “orchestration” of multiple solution approaches across the domains they originated in. The solutions to the technical challenges revolved around the lowest possible “technical” complexity, which contradicts the increasingly demanding requirements of the “conceptual” view of full and comprehensive data integration (i.e., real-time, standing interfaces, etc.). Extraction and processing logics were decoupled without affecting the requirements on “timeliness” and “simultaneously” reduced the resource consumption on the data source system. Likewise, organisational solutions were simpler than would have been expected. Granular business process improvement [25] and employing checklists [26] proved highly effective. Although these methodologies are well-known, they apparently had not been applied consistently in this setting. The strategic challenges were solved by combinations of game theory and contract mechanism design. This was facilitated by clarity on the objectives and the existing business relationships.

## 4 Conclusions and Outlook

This paper provides an overview of the challenges faced by supply networks striving towards improved visibility across strategic, organisational, and technical domains in the proposed DSN data integration lifecycle phases of engineering of data integration, daily operations management, and end-of-life management. This aims to effectively operationalize “visibility” towards transparency and predictability with the overall objective to achieve agile DNSs. This is particularly relevant for SMEs and SCs where SMEs are involved as CMs and/or OEMs. The limitations of the case study are the use of a single case study and shifting investigations of solution approaches to future work. In future work solution approaches, cybersecurity, and the impact of increased “agility” on the organisational setup domain.

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