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Boundary Objects for Integrating Maintenance into Strategic Procurement of Battery Production Equipment

A Case Study of Northvolt

Master's thesis in Supply Chain Management & Management and Economics of Innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY

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Abstract

This master's thesis investigates how maintenance considerations can be effectively integrated into the strategic procurement of battery production equipment, with a focus on Northvolt, a Swedish pioneer in battery manufacturing. As the battery industry grows rapidly to meet the increasing demand for electrification, ensuring robust procurement and maintenance processes becomes critical for operational efficiency and sustainability. The study addresses three primary research questions: mapping the procurement process and its associated difficulties and mitigation strategies, identifying critical maintenance-related challenges, and developing practical solutions to bridge procurement and maintenance functions.

An abductive research approach was adopted, combining semi-structured interviews with a case study of Northvolt, supported by a literature review of strategic procurement, maintenance, and organizational coordination. This methodological design enabled iterative improvements between empirical insights and theoretical understanding throughout the study.

Key findings identify procurement and maintenance challenges such as supplier dependency, departmental misalignment, and documentation gaps. In response, five interventions are conceptualized as boundary objects: 1) human intermediary, 2) cross-functional workshops, 3) cross-functional RFQ framework, 4) acceptance test framework, and 5) expert regional supplier-specific Teams (ERSSTs), each designed to strengthen coordination and improve long-term equipment performance.

Together, these form a system of boundary objects intended to support the early and systematic integration of maintenance considerations into the strategic procurement process. Beyond addressing firm-specific issues, this contribution offers practical insights for other industrial actors seeking to improve cross-functional collaboration and equipment lifecycle outcomes in complex manufacturing environments.

Keywords: Battery Production Challenges, Battery Production Equipment, Boundary Objects, Purchasing, Maintenance, Strategic Procurement, Theoretical boundaries.

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Simon Johansson Sjösten & Simon Oredsson

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Glossary

To enhance clarity while reading report, this section provides a comprehensive list of the acronyms used throughout this thesis:

AHP – Analytical Hierarchical Process

BOM – Bill of Material

ERSST – Expert Regional Supplier Specific Team

ESI – Early Supplier Involvement

FAT – Factory Acceptance Test

JDA – Joint Development Agreement

RFQ – Request for Quotation

RFI – Request for Information

SAT – Site Acceptance Test

SIT – Site Integration Test

SLA – Service Level Agreement

TCO – Total Cost of Ownership

1 Introduction

This chapter introduces the context for the thesis, focusing on the ongoing green transition and the growing need for sustainable battery production within Europe. It begins by outlining the broader background, including the role of electrification, supply chain challenges, and the strategic significance of regional battery manufacturing initiatives. The chapter then presents the purpose of the study and explaining the aim to explore the integration of maintenance considerations into strategic procurement processes for battery production equipment. To guide this exploration, a set of research questions is introduced. Finally, the chapter outlines the practical limitations of the study, including constraints related to data collection and access to key stakeholders.

1.1 Background

A large challenge of the 21st century is coping with climate change and its consequences. In line with this, the European Union has set clear targets in becoming climate neutral by 2050 (European Commission, 2021), with the intermediate goal of reducing EU's total greenhouse-emissions by 90% in 2040 compared to 1990 (European Commission, 2024). To realize this green transition many different initiatives are required, where changing mobility practices by increasingly electrifying the fleet is pointed out as one key driver (Krishnan et al., 2024). However, continuing an increasing electrification of the mobility sector creates significant challenges in ensuring supply of batteries and other key components. According to Fleischmann et al. (2023) the demand of lithium-ion batteries is expected to grow by 27% on an annual basis until 2030, while the European Commission (2024) points out an anticipated increase of 60% for EV-cars and 40% for heavy-duty vehicles until 2040.

Manufacturing of lithium-ion batteries, the key component for a successful electrification, is currently heavily dominated by Chinese actors. According to The International Energy Agency (2023), around 76% of all lithium-ion supply originated from China in 2022, meanwhile, it is estimated to decline marginally to just below 70% by 2030 due to ongoing projects in other regions. One of these initiatives is the European Battery Alliance (EBA) with the aim to create large-scale manufacturing of lithium-ion batteries, and thus more regionalized supply within EU (European Commission, 2018).

Ensuring a more localized supply of key components for electrification is fundamental due to rising uncertainties in the macroenvironment. One of the reasons is due to climate concerns, where Woetzel et al. (2020) points out that the probabilities of supply chain disruptions caused climate change in certain regions could increase by up to four times by 2040. Furthermore, geopolitical tensions across regions are increasing with ongoing conflicts posing threats for disruptions in global supply chains. Therefore, the concepts of onshoring and bringing supply

chains more local are increasingly utilized concepts to increase resiliency and manage those risks (Kilpatrick, 2022).

In line with these risks, the European Commission (2018) has set targets to break dependency on foreign battery production and instead bring it more locally. One clear step towards this was the establishment of Northvolt's Gigafactory (a large factory producing large quantities of batteries for electric vehicles, "Northvolt Ett" in northern Sweden. Other notable gigafactories in Europe are Tesla in Germany, Samsung in Hungary and LG-Energy located in Poland. These firms are of American or Asian descent and are establishing a presence in Europe with these gigafactories. With Northvolt's factory, they did not only strive to break dependence on imported batteries, but also to utilize green energy to massively reduce the carbon footprint of their battery-cells compared to foreign producers using coal as primary energy source (Northvolt, 2023; Northvolt, n.d.).

Realizing this green transition does, according to the European Environment Agency (2023), require annual investments of up to 500 billion EUR within the European renewable energy industry. These investments are vital for advancing key sectors, such as the production of renewable energy and batteries for electrification. However, the European battery production industry is currently facing significant financial challenges. One of these issues is rising raw material prices, making large-scale production of affordable battery cells increasingly difficult (European Court of Auditors, 2023). As a result, the entire European industry is struggling to remain competitive and sustain its operations.

With battery production being associated with large upfront investments and costs, there is a need to take care of the purchased equipment in a responsible way. One way of doing this, according to Lüdeke-Freund et al. (2019), is by ensuring proper maintenance extending the lifetime of equipment and thus reducing the total cost of ownership (TCO). Consequently, the ongoing research-project **MATTER@SCALE**, conducted by Chalmers University of Technology and funded by Vinnova, focuses on exploring how to implement this concept in the Swedish battery production industry (Vinnova, 2023). The importance of determining characteristics such as maintainability throughout the lifetime of the purchase at an early stage is reflected in strategic purchasing.

The strategic purchasing function involves aligning the procurement process with an organization's broader strategic objectives to generate a sustainable competitive advantage (Carr & Smelter, 2004). This approach differs from traditional one-dimensional procurement processes where cost is the main deciding factor. While strategic purchasing emphasizes long-term value creation by considering factors beyond cost, such as quality, supplier relationships, and sustainability (Carr & Smelter, 2004), it does not explicitly involve maintenance of production equipment. Lüdeke-Freund et al. (2019) highlights the importance of maintenance in extending the lifespan of assets such as production equipment, and other machinery. The processes of involving aspects of maintenance in the strategic purchasing process could lead

to a more holistic purchasing approach, ensuring that investments remain efficient and sustainable over a longer period of time.

1.2 Aim of Study

This master's thesis aimed to explore how maintenance considerations can be integrated effectively into the strategic procurement of production equipment in the battery industry. In the strategic part of procurement, various criteria are used to define characteristics of desired the desired equipment, but these may not always consider long-term maintenance needs. By identifying key challenges in both procurement and maintenance, the study intended to improve cross-functional alignment between these departments in the acquisition process of new production equipment. To achieve this, the thesis applied the concept of boundary objects as a tool to bridge organizational and functional gaps based on the identified challenges. Finally, the goal was to support a procurement process where maintenance considerations are considered at an early stage, contributing to extended equipment lifespans, minimizing issues with operational downtimes, and reducing TCO.

1.3 Research Questions

To clarify the purpose of this study, the aim was further broken down into clear research questions navigating the coming parts of this report. These three questions are sequential, meaning that the output from the first two research questions worked as important inputs for the third one. The first two questions were designed to understand the current situation by identifying key challenges in strategic procurement of battery production equipment, as well as critical requirements and concerns from a maintenance perspective. Finally, the third research question was built on these findings by exploring how the identified challenges in procurement and maintenance can be addressed by using boundary objects, ultimately contributing to the aim of bridging the gap between procurement and maintenance in the acquisition-process of battery production equipment. Therefore, the following RQs were designed:

- **RQ1:** What challenges exist in the strategic procurement of battery production equipment, and how have they been mitigated?
- **RQ2:** What maintenance-related challenges and requirements are critical to address during the strategic procurement of battery production equipment?
- **RQ3:** What boundary objects can bridge the challenges between strategic procurement and maintenance during the acquisition of battery production equipment?

1.4 Limitations

This study was subject to some limitations that may have influenced the scope and depth of its findings. One significant limitation was the availability of financial resources restricting the travel to Northvolt's site. As a result, all interviews with Northvolt staff were conducted online.

Additionally, access to Northvolt staff was limited to the first ten weeks of the study. During the 10th week of the study, Northvolt filed for bankruptcy, impacting on the possibility of contacting interviewees for follow-up questions. These constraints may have affected the number of interviews conducted and the range of perspectives gathered. Despite these limitations, efforts were made to optimize the interview process within the given time, making it possible to conduct a total of 12 interviews at an early stage, ensuring that the data collected remained as comprehensive and representative as possible.

2 Theory

To understand how firms can effectively manage complex production systems such as battery manufacturing, it is essential to first explore the theoretical foundations that highlight key organizational and operational functions. This chapter introduces central concepts including 1) procurement, 2) maintenance-related concepts, 3) theoretical boundaries, 4) organizational structure, and 5) battery production, each of which plays a crucial role in ensuring industrial efficiency, innovation, and strategic alignment. Together, these perspectives provide a comprehensive understanding of how theory informs practice in high-technology manufacturing environments.

2.1 Procurement

Although procurement is closely related to purchasing, they are not completely synonymous. Purchasing is typically viewed as an operational part of the broader procurement process. While purchasing is mainly related to the ordering of goods, procurement also involves preparatory activities. According to Van-Weele and Rozemeijer (2022), determining specifications, choosing suppliers, negotiating contracts, ordering, expediting, and evaluating the purchase are all components of the procurement process. They further divide these six activities into tactical and operational purchasing where the first three are considered tactical and the remaining three are operational. In addition to these two traditional parts of procurement, there is a third more holistic perspective in terms of strategic purchasing. Here, the focus is on aligning purchasing with the overall business strategy to ensure a favorable market position in the long-term (Van-Weele & Rozemeijer, 2022).

2.1.1 Strategic Purchasing

Strategic purchasing represents a shift from the traditional procurement function to a strategic function where the long-term success of the firm is at the center of decision-making (Ellram & Carr, 1994). This shift involves greater integration of the purchasing function with overall strategy objectives, positioning itself for long-term planning and the strategic goals of the firm (Cavinato, 1999; Paulraj et al., 2006).

A key component of strategic purchasing is its ability to obtain supply integration between buyers and suppliers. The creation of this collaboration can be broken down to four pillars: 1) relational integration, 2) process integration, 3) information integration, and 4) supply integration (Paulraj et al., 2006). The first pillar emphasizes the importance of long-term relationship with a limited number of suppliers. These types of partnerships can be categorized as a strategic partnership, where the buyer and seller commit to partnerships benefiting both parties. Caniëls and Gelderman (2005) highlight that in the strategic quadrant of the Kraljic matrix, maintaining strategic partnerships is essential due to the high profit impact that these partnerships have (Kraljic, 1983).

The second pillar is about using strategic partnerships to extend the processes of integration outside of the firm (Paulraj et al., 2006). This is to ensure the seamless coordination of logistics such as distribution and transportation between firms to enhance supply chain efficiency. This collaboration between firms could help reduce delays and ensure the smooth transportation of materials across the supply chain.

The third pillar communicates effective information flows between firms to jointly find solutions to problem that arise (Paulraj et al., 2006). By establishing a clear communication channel between firms, critical information can be shared to resolve potential problems before they escalate into significant issues.

The fourth and final pillar of supply integration is the usage of cross-organizational teams. These teams bring together individuals from both the buying and supplying firm to collaborate and share ideas between them (Paulraj et al., 2006). This approach aligns with Chesbrough's (2003) concept of open innovation, which highlights the importance of sharing information between firms to drive innovation. By collaborating across organizational borders, firms can exploit the expertise of other actors to create more value for all involved.

2.1.2 Tactical Purchasing

After the strategic part, there are preparatory steps that must be finished before ordering products. In the linear purchasing process developed by Van-Weele and Rozemeijer (2022), this is referred to as tactical purchasing, consisting of three sequential steps.

The first step is to set clear specifications of what is needed. This often requires input from individuals beyond the purchasing department. The complexity of this process depends on the product complexity and the commercial uncertainty (Van-Weele & Rozemeijer, 2022). Products considered high in both factors require extensive cross functional involvement in the purchase, while simpler purchases can be handled by purchasing alone.

According to Van-Weele and Rozemeijer (2022), high product complexity includes customized products, first-time purchases, or complex technologies, while high commercial uncertainty involves large upfront investments with an expected long-term impact. Therefore, the involvement of stakeholders in specification-setting should depend on the product characteristics. However, conflicting priorities between different departments must be considered. For example, purchasers often prioritize having many potential suppliers to lower prices, while engineering favors closer relationship with fewer suppliers to co-develop solutions (Moses & Åhlström, 2008). Therefore, involving both parties in setting the specifications can bridge siloes between the departments.

Once the organization understands the type of purchase and who to involve, it is time to set specifications. This is a preparatory step, defining the product requirements and narrowing down potential suppliers. Specifications can either be functional or technical (Van-Weele & Rozemeijer, 2022). Functional specifications describe desired outcomes without specifying how to achieve them, allowing more freedom and encouraging innovation (Edquist & Zabala-

Iturriagoitia, 2020). In contrast, technical specifications are more detailed, explaining dimensions, materials, and features. While these offer clarity, they can, according to Van-Weele and Rozemeijer (2022), lead to overspecification and higher costs without added performance. Therefore, the level of details in specifications affects flexibility in supplier selection.

The second stage of tactical purchasing is supplier selection. Once specifications are set, organizations conduct supply market research to fill a list with eligible suppliers (Van-Weele & Rozemeijer, 2022). The buying organization then approach the suppliers on the list with a request for information (RFI), to obtain the desired information and their references from previous similar projects. Based on this along with potential audits evaluating the suppliers' competences, the list of suppliers is narrowed down. The remaining suppliers are then asked to submit their bids in line with the specifications, through a request for quotation process (RFQ) (Van-Weele & Rozemeijer, 2022).

When bids from different suppliers have arrived, the organization evaluates them to determine the best fit. There are many different methods for doing this. In a literature review of this area, Mukherjee (2016) divided the methods into three different categories of single models, while highlighting that multiple single models often are combined to integrated models for supplier selection. The three types are: Statistical models including regression and cluster analysis, artificial intelligence tools, and mathematical models. The latter are most commonly used due to their simplicity (Mukherjee, 2016). Examples of these models include the Analytical Hierarchical Process (AHP) and TCO-based methods.

In the literature review, Mukherjee (2016) identified AHP as the most common method for supplier selection, both as a single model and as a component in integrated models, due to its simplicity. Nydick and Hill (1992) who first presented the method, outlined some steps on how to apply it in practice. AHP is especially useful when evaluating multiple criteria, so the process begins by assigning relative weights to criteria through pairwise comparisons based on their importance. These weights are often derived from managerial judgment, and involving various departments can enhance its objectivity. The pairwise comparisons are then placed in a matrix, and mathematical calculations determine their relative importance (Nydick & Hill, 1992). Suppliers are then similarly assessed for each criterion, and the weighted performance scores are aggregated to rank suppliers.

Other methods mentioned by Mukherjee (2016) was based on the TCO-concept. As described by de Boer et al. (2001), TCO considers all quantifiable costs over the products' life cycle, not just transaction costs, but also pre- and post-transaction costs. Therefore, costs occurring during the lifetime of the purchased asset shall be considered prior to the actual purchase. For expensive production investments like machinery, Ellram (1995) points out yield, uptime, and maintainability as important considerations before a purchase. Therefore, investments in expensive assets shall not merely focus on the price-tag, but also on aspects that drive operational expenses during the lifetime of the asset.

The final step in tactical purchasing is contract negotiation with the selected supplier. In this process all the legal specifications for the upcoming relationship are to be determined. Example of topics included are prices, terms of payment, agreements on how to order and additional aspects such as penalty clauses and warranties (Van-Weele & Rozemeijer, 2022). For instance, prices can be fixed for the duration of the contract or variable depending on some specified milestones. Furthermore, for terms of payment the discussions are mainly focused on how many days the buyer had to pay the invoice after delivery, or if the payments shall be in advance. Finally, penalty clauses and warranties in the contract determines what the consequences are for either party when the agreed terms and liabilities are not met (Van-Weele & Rozemeijer, 2022).

2.1.3 Operational Purchasing

When all preparatory work is completed and contracts are signed with the chosen suppliers, the operational phase of procurement begins. The first stage is ordering of products from the suppliers. For routine buys, where goods are purchased repetitively over a longer period, the process for ordering is often clarified in a call-off-agreement finalized in the contracting stage (Van-Weele & Rozemeijer, 2022). These agreements specify quantities and prices in advance, allowing the buyer to order as needed without further negotiation. For less frequent purchases, more details must be provided with each order, including product description, quantity, invoicing address, and delivery time and place (Van-Weele & Rozemeijer, 2022). Therefore, the ordering process varies depending on purchase type and supplier relationship.

Expediting is the second step in operational purchasing and involves monitoring the process from order placement to delivery. Van-Weele and Rozemeijer (2022) describe four approaches: exception expediting, routine status check, advanced status check, and field expediting. The first is reactive, initiated by internal alerts about delays. The latter three approaches are proactive. In “routine status check” the buyer contacts the supplier some days before delivery to ensure there will be no delays. In “advanced status check”, the buyer contacts the supplier more frequently at regular intervals. For the final approach, “field expediting”, the buying firm places an inspector at the suppliers’ site to ensure monitor progress. As material criticality increases, so does the required effort, with each of those approaches demanding more effort and oversight than the previous one (Van-Weele & Rozemeijer, 2022). Thus, the suitability of different expediting approaches depends on context and material importance.

The final step is performance evaluation, where the buyers’ role extends beyond the finalized delivery, including enforcing contract terms such as warranties and penalties (Van-Weele & Rozemeijer, 2022). Apart from this, buyers also update internal files keeping track of the suppliers’ performance in terms of quality, delivery-precision and innovativeness. This not only supports supplier development but also improves future supplier selection by providing insights into past performance (Van-Weele & Rozemeijer, 2022).

2.1.4 Purchasing Process Models

Building on the strategic, tactical, and operational dimensions of purchasing, various models have been developed to visualize the purchasing process. In a literature review, Bäckstrand et al. (2019) identified five different types of purchasing process models, classified by their characteristics.

The first type, the decision-making models, mainly works as a tool assisting purchasers in deciding whether to buy a specific product (Bäckstrand et al., 2019). One example for this type is the one by Rados (1970), consisting of a set of binary questions guiding the purchasers to decide if a certain product shall be purchased or not. While these models not explicitly include tactical purchasing, they aid in evaluating products from a supplier. Though, they do not compare multiple suppliers, they are still used to select suppliers, relating them to the tactical dimension.

The second type is linear process models, which Bäckstrand et al. (2019) identify as the most common for visualizing the purchasing process. The linear purchasing model by Van-Weele and Rozemeijer (2022), along with some adaptations of it, represented most models within this category. This model divides the overall purchasing process into six steps, with three tactical parts and three operational parts as presented in the previous paragraphs. A visualization of this model can be seen in Figure 1. One thing these models have in common is that most of them start with identifying the need while ending with a step where the desired product or service is delivered (Bäckstrand et al., 2019). Therefore, these models mainly focus on the tactical and operational parts of purchasing while the strategic considerations are left out.



Figure 1: Visualization of the linear purchasing process model

The third variant of purchasing process models are strategic process models, which focuses primarily on the strategic parts of purchasing. Rather than detailing individual purchasing steps, these models emphasize the alignment of purchasing strategy with the broader firm strategy (Bäckstrand et al., 2019). This alignment is achieved by starting with the overall firm strategy and breaking it down into further detail in the context of purchasing.

For this, Hespig and Schiele (2015) present a model with five hierarchical steps, see figure 2. It begins with the firm's overarching strategy and ends up with specific supplier strategies for each purchase-category. Once the firm strategy is defined, each function in the organization must translate the business goals into department-specific targets aligned with the overall objectives of the organization. These targets are further broken down into category-specific strategies, considering factors such as supply risk and financial impact, as outlined in Kraljic's matrix (1983). The category-specific strategies are then executed using sourcing levers, defined

by Hesping and Schiele (2015) as activities or tactics that help achieve category goals. Examples include international sourcing, which reduces costs through supplier competition or product optimization by establishing close, long-term relationships for co-development of products (Schiele et al., 2011). Finally, the strategy should be adapted to specific supplier-relationships, identifying suitable ways of (Hesping & Schiele, 2015), where the four pillars by Paulraj et al. (2006) can be adapted based on the type of relationship.

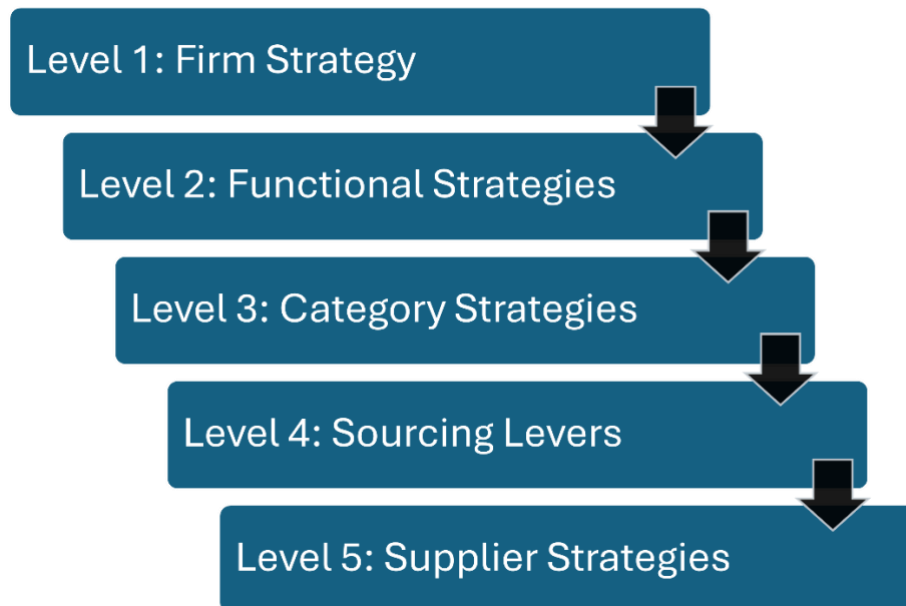


Figure 2: Visualization of a strategic purchasing process model

In the fourth category, Hesping and Schiele (2015) groups cyclical models, see Figure 3. In contrast to the linear process-models, these highlights how experience from past purchases can inform future ones. They include the same content as the linear purchasing model by Van-Weele and Rozemeijer (2022), but also highlighting how the evaluation phase serves as valuable input for initiating new purchasing processes. The fifth and final category stated is the Hybrid-Linear-Cyclical models, also presented by Hesping and Schiele (2015). These models distinguish between finding new suppliers and managing existing ones. The former follows a process similar to the tactical steps in linear models, while the latter is represented as a cyclical process including supplier evaluation, development and relationship management, key aspects in ongoing supplier collaboration (Hesping & Schiele, 2015).

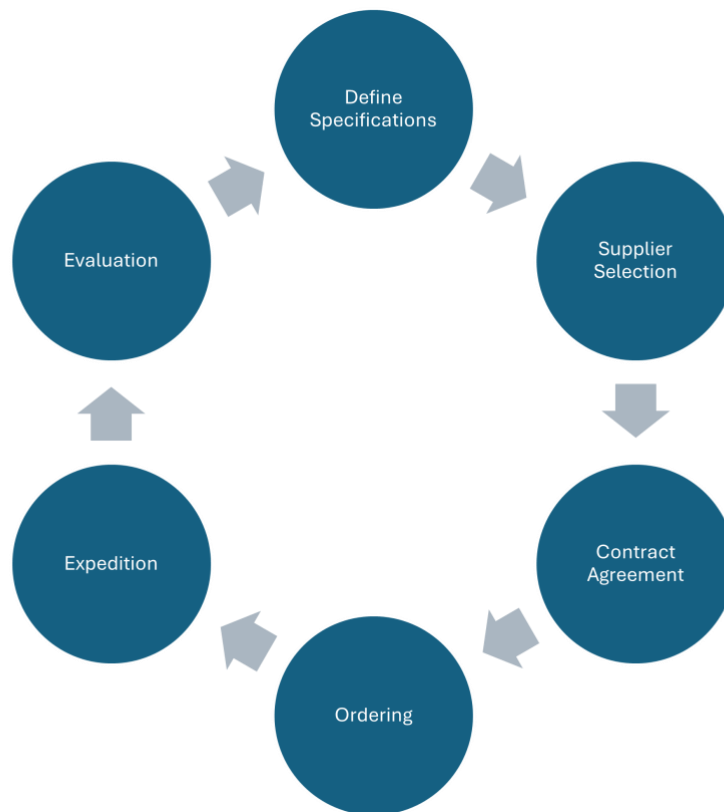


Figure 3: Visualization of a cyclical purchasing model

2.2 Maintenance

In addition to procurement, another key factor in achieving operational reliability is maintenance, a critical function within manufacturing and production systems ensuring that equipment remains operational, safe, and efficient. It involves a combination of technical, administrative, and managerial actions aimed at retaining or restoring an item to a state in which it can perform its required function (Swedish Institute for Standards [SIS], 2022). According to Garg and Deshmukh (2006), maintenance should be integrated into the production system, not treated as a standalone function, to ensure that maintenance can be a part of the strategic decision-making process. Along with energy costs, maintenance can be one of the largest components of a firms' operational budget, making its input crucial.

Mobley (2002) categorizes maintenance into three main types: preventive maintenance, which involves scheduled maintenance tasks to avoid unexpected failures. Predictive maintenance, which relies on real-time monitoring and historical data to anticipate failures. Lastly, run-to-failure maintenance, where repairs are conducted reactively after equipment breaks down completely.

2.2.1 Preventive maintenance

Preventive maintenance refers to scheduled tasks, typically found in supplier-provided maintenance plans, designed to prevent equipment failures by servicing at predetermined intervals. This approach aims to maintain operational efficiency, extend asset lifespan, and minimize unexpected breakdowns disrupting production (Mobley, 2002). A preventive

maintenance strategy typically follows a time-based or usage-based schedule, where tasks such as inspections, lubrication, and component replacements are conducted after a specified time or number of operating hours. The reasoning behind this approach is supported by the bathtub curve, which shows failures are more common early and late in an asset's life cycle (Mobley, 2002).

Well-implemented preventive maintenance programs can lead to lower maintenance costs compared to other reactive strategies like corrective or run-to-failure maintenance. Garg and Deshmukh (2006) highlight that preventive maintenance helps optimize resource allocation by scheduling maintenance activities before failures occur, reducing costly unplanned downtime and improving overall reliability of the equipment. However, they also emphasize that an overly preventive maintenance schedule can result in unnecessary servicing, leading to wasted resources if equipment does not actually require maintenance at the scheduled time.

2.2.2 Predictive maintenance

Predictive maintenance is a condition-based maintenance strategy that aims to assess the state of equipment and predict potential failures before they occur. Unlike preventive maintenance, which follows a fixed maintenance schedule, predictive maintenance relies on real-time monitoring to learn when equipment needs maintenance. This method reduces unnecessary maintenance that would otherwise be performed under a preventive maintenance schedule (Mobley, 2002). According to Garg and Deshmukh (2006), predictive maintenance allows for this shift from reactive and preventative maintenance towards a more data-driven approach that involves the use of advanced diagnostic technologies to understand when maintenance is necessary.

With the advancement in industry 4.0, including the Internet of Things (IoT) and artificial intelligence (AI), predictive maintenance is becoming more effective and widespread. The integration of IoT enables continuous real-time monitoring of equipment conditions (Liu et al., 2022). This means that, with the combination of AI and IoT, firms can take more informed decisions with regards to maintenance scheduling.

Traditional predictive maintenance focuses on obtaining information on individual assets such as production equipment (Mobley, 2002). However, with the advancement of IoT-based systems for predictive maintenance, a manufacturing plant-wide system can monitor the entire industrial environment (Liu et al., 2022). This means that the focus of maintenance can transform from an individual perspective to a system perspective. One of the challenges with a system-wide perspective however is the significant financial investments of sensors to gather data, as well as in data processing infrastructure (Liu et al., 2022).

2.2.3 Run-to-failure maintenance

Run-to-failure maintenance is a reactive maintenance strategy where equipment and machinery are allowed to operate until it fails, at which point repairs or replacements are performed. This approach follows the principle of "if something is not broken, do not fix it",

meaning that no preventive actions are taken to extend the lifetime of equipment and machinery (Mobley, 2002).

The run-to-failure approach is a no-maintenance strategy in which firms do not invest in proactive maintenance until a failure happens. This method requires firms to be highly responsive to unexpected breakdowns and to have sufficient spare parts and repair resources available. While this approach may be cost-effective for non-critical, low-cost assets, it is generally considered the most expensive maintenance strategy for critical equipment due to the high costs associated with unexpected downtime, expedited repairs, and spare part inventories (Mobley, 2002).

2.2.4 CE-Certification

CE-Certification (*Conformité Européenne*) of a product signifies that products comply with essential health, safety, and environmental requirements of the European Union (EU) legislation (European Commission, 2020). The CE mark is the manufacturer's declaration that a product meets all the requirements set by the European Union and can therefore be sold legally throughout Europe. Rather than a quality indicator, it could be seen as a conformity mark that shows a product meets the essential requirements (Ballor, 2022). Instead of adapting a product to specific national laws, the CE mark allows for businesses to freely circulate their products throughout Europe (Kanjevac Milovanović et al., 2011). CE marking is valid in multiple industries and different product types, from industrial machinery and electronics to medical devices. Beyond this, firms have found that the CE logo can be seen as a quality stamp in global markets, which allows them to gain a differentiation advantage compared to products from the local area (Ballor, 2022).

2.2.5 Bill of Material (BOM)

A Bill of Materials (BOM) serves as a foundational document in manufacturing, detailing the components and materials required to produce a final product. It acts as a structured representation of a product's composition and plays a vital role in manufacturing planning, cost estimation, and supply chain management (Rusk, 1990). BOMs exist in different forms to meet specific functional needs. The engineering BOM is primarily used during the product design phase to outline the structure of a product. The manufacturing BOM is adapted for production planning, considering assembly sequences and constraints (Chang et al., 1997). A well-structured BOM can enhance manufacturing flexibility and efficiency by reducing inventory levels, improving responsiveness to changes, and supporting Just-In-Time production methods.

2.2.6 Spare-Parts Management

Spare parts are parts that can be changed or modified in a machine and are stocked to keep equipment functioning to operational efficiency (Zhang et al., 2021). These spare parts can be categorized into two types: repairable parts and non-repairable parts. The management of these categories differs, with repairable parts being more complex than non-repairable parts.

With repairable parts, multiple stakeholders can be involved such as repair workshops and different spare part suppliers. In contrast, non-repairable parts are generally replaced with a new part making them easier to keep in stock (Arts, 2014).

The management of spare parts differs significantly depending on whether the parts are repairable or non-repairable. With repairable parts it's necessary to establish reverse flows which include collection, inspection, repair, and restocking (Zhang et al., 2021). The reverse flows are complex and require more involvement than traditional non-repairable parts. Furthermore, the lead times for repairable parts are influenced by factors such as repair capacity and the time required to perform repairs. On the other hand, non-repairable parts are discarded after use and do not re-enter the supply chain. Since these parts are replaced instead of repaired, keeping stock of them is generally more predictable.

2.2.7 Asset management

Asset management is the coordinated activity of an organization to realize value from its assets across their lifecycle. This includes planning, acquisition, operation, maintenance, and disposal, with the aim of optimizing performance, reducing costs, and minimizing risks (International Organization for Standardization [ISO], 2014). Asset management has evolved to incorporate not only technical and financial considerations, but also strategic alignment with organizational goals. Amadi-Echendu et al. (2010) emphasize that for asset management to be efficient it requires the integration of engineering, economics, and management to ensure assets contribute effectively to value creation. A key aspect of asset management is understanding the asset's condition and criticality to prioritize resource allocation and making informed investment decisions. The ISO 55000 standard provides a global framework for establishing, implementing, and improving asset management systems, promoting a structured approach (ISO, 2014).

In this context, procurement plays a critical role, particularly when maintenance considerations are integrated early in the acquisition phase. Gaus et al. (2022) emphasize that incorporating life cycle cost information into procurement decisions can support long-term economic sustainability. While much of an asset's total cost is known to arise during its operational phase, procurement strategies must also consider how maintenance will be delivered. For example, performance-based maintenance contracts have been shown to improve cost-efficiency and reliability outcomes by incentivizing suppliers to focus on long-term asset performance (Straub, 2009). Aligning maintenance and procurement decisions thus supports the broader asset management objective of maximizing value creation across the asset lifecycle.

2.3 Organizational structure

While asset management focuses on maximizing the value of physical resources, the organizational structure determines how effectively people and processes align to support those goals. The structure of an organization lays the foundation for how work is coordinated,

decisions are made, and goals are pursued (Mintzberg, 1980). It shapes how individuals and departments interact, how resources are distributed, and how adaptable the organization can be in a changing environment. Selecting an appropriate structure is not a one-size-fits-all decision, where different organizational structures are more fitting in certain environments than others (Mintzberg, 1980).

This chapter explores how organizational structure affects not only the efficiency of core functions like procurement, but also the ability to drive innovation in organizations. By examining different ways of organizing procurement activities, and fostering innovation, the chapter aims to provide a comprehensive understanding of how structure affects organizational performance.

2.3.1 Organizing Procurement

Procurement departments can be structured in different ways, depending on both internal and external factors. These factors have been studied to identify contingencies, conditions under which specific structures are preferable. This approach, known as contingency theory, focuses on aligning organizational structure with the macroenvironment (Glock & Hochrein, 2011). Therefore, these contingencies impact how purchasing departments are structured in different dimensions. According to Bals et al. (2018), the purchasing departments are structured with regards to both macro- and micro-level dimensions. The macro-level dimensions determine how procurement activities are grouped on a higher level, while the micro-level aspects specify how the purchasing activities are executed within the overall structure.

At the macro level, purchasing departments can be structured based on four different dimensions; geography, category, business-unit, and activity (Bals et al., 2018). In a geography-based structure, the department is divided into separate units responsible for sourcing from specific regions, allowing for better alignment with local suppliers, regulations, and market conditions. For the category-based structure, the department is divided into sub-divisions being responsible for all products within a specific category, enabling specialization and deeper expertise within each product group. Followingly, dividing the department based on business-units makes each sub-department focusing on distinct customer segments, such as corporate clients or individual consumers. Finally, in an activity-based structure, each sub-department focus on niched parts of the purchasing process, such as the tactical sourcing versus operational purchasing. According to Bals et al. (2018), the selection among these macro-level dimensions come with different advantages which can be seen below in Table 1.

Macro-Level Dimension	Description	Advantage
Geography	Departments structured around and sourcing from distinct geographical locations.	<i>Economies of Learning</i> with special knowledge about local market requirements.

Category	Purchasing structure divided to focus on specific product groups (e.g. raw material or services).	<i>Economies of Scale</i> by bounding volumes across business units.
Business Unit	Purchasing divided into sub-departments focusing on different business lines (e.g., B2B or B2C).	<i>Economies of Learning</i> by understanding unique needs and priorities, enabling tailored work-processes for different business units.
Activity	Division of departments focusing on specific steps in the purchasing process (e.g., tactical sourcing or operational buying)	<i>Economies of Processes</i> by standardized and efficient workflows in each buying step.

Table 1: Summary of macro-level dimensions.

While purchasing departments are structured according to macro-level dimensions, they can be configured in various ways at the micro-level. These micro-level dimensions define how the overall structure is implemented in practice, with specific configurations often depending on the chosen macro-level setup (Bals et al., 2018). In their framework, Bals et.al (2018) identify five dimensions: the degree of centralization, formalization, standardization, specialization, and participation. All these five dimensions by Bals et al. (2018) are briefly explained in Table 2 below, while the degree of centralization is discussed more detailed in the following section.

Micro-Level Dimension	Description
Degree of Centralization	Whether decision-making authority is concentrated centrally in the organization, or if it is distributed across locations.
Degree of Formalization	Extent to which procurement tasks, rules, and procedures are standardized and documented.
Degree of Standardization	Degree to which procurement processes follow uniform guidelines across the company.
Degree of Specialization	Level of expertise and role differentiation in procurement activities.
Degree of Participation	The degree of cross functionality of which organizational members are involved in procurement decision-making.

Table 2: Description of micro-level dimensions

The degree of centralization in purchasing departments is a continuum, with distinct advantages at both ends. A centralized structure provides greater control, while a decentralized approach offers increased flexibility, thus there is an inherent trade-off in this decision (Bals et al., 2018). In centralized system, a single department handles procurement for all business units, ensuring consistency and enabling cost savings through economies of (Van-Weele & Rozemeijer, 2022; Bányai, 2024). However, this can lead to slower processes and reduced responsiveness. In contrast, decentralized purchasing allows individual business units

to manage their own procurement, enabling faster decision-making and better adaptation to specific products, suppliers, or regional needs. However, this flexibility can come at the cost of higher expenses due to fragmented negotiations and reduced alignment with company-wide procurement policies (Bányai, 2024).

Given the distinct advantages of centralized and decentralized purchasing, their effectiveness depends on the contextual setting. Studies by Glock and Hochrein (2011) and Bals et al. (2018) identify several contingencies that influence this decision, which can be grouped into four categories: Organizational, External, Product-Specific, and Purchase-Situation related factors. Organizational factors highlight the need to adapt purchasing strategy with the firm’s strategic direction, for example innovation-driven firms may require a more flexible, decentralized approach, while cost-leadership-strategies often favor centralized models to leverage economies of scale (Bals et al., 2018). External factors such as environmental complexity, including the number of supply sources and the pace of technological development. Finally, product-specific and purchase situational factors further influence the ideal configuration of the purchasing organization. In Table 3 below factors impacting the buying organization according to Glock and Hochrein (2011), is presented.

Contingency	Description
Purchasing Volume	Higher volumes purchased increases the probability of centralization to reduce costs.
Technical Complexity	More complex products require many resources leading to increasing size of the buying organization and a higher degree of centralization.
Importance of Purchase	Higher importance of the product and the purchase in general elevates uncertainty, increasing the size of the buying organization and move towards a higher degree of centralization.
Time Pressure	Purchasing tasks with high time-pressure require faster decisions, thus often smaller buying organizations.
Level of Risk	With increasing risks and uncertainties, there is a larger need to access information to reduce the overall ambiguity. Often leading to larger buying centers and higher degree of centralization.
Buying Stage	Earlier stages of the process more uncertain due to path dependency and therefore it is often more people involved at earlier stages.
Degree of Novelty	New buying situations are more unfamiliar creating a need for diverse competences and information, thus often being associated with larger buying centers.

Table 3: Contingencies affecting the buying organization based on Glock and Hochrein (2011)

2.3.2 Organizing for innovation

Innovation is a critical driver of competitiveness and long-term success for organizations operating in uncertain environments. However, fostering innovation requires deliberate structuring of both the organization as well as the business model, to balance efficiency and creativity (Teece, 2010). The challenge lies in how firms can structure themselves to achieve

ambidexterity, balancing the exploitation of existing resources while also exploring new opportunities (Raisch et al, 2009).

The design of an organization significantly influences its ability to be innovative. While traditional hierarchical structures support operational efficiency, they often hinder creativity and limit cross-functional collaboration (Pugh, 1990). To overcome these limitations, many firms adopt alternative structures, such as matrix organizations, which combine functional and project-based elements to facilitate collaboration across departments and teams (Sy & D’Annunzio, 2005). However, this added complexity can introduce challenges, including role ambiguity, conflicting priorities, and siloed thinking. Without clear communication, defined responsibilities, and strong accountability mechanisms, matrix structures risks becoming sources of inefficiency rather than enablers of innovation. One approach to managing this complexity is the use of organigraphs, visualizing work processes and interdependencies in ways that help clarify dynamic relationships within the organization (Mintzberg, 1999). By understanding the flow of information, managers can foster and promote a more collaborative environment, ultimately promoting organizational innovation.

A fundamental tension in organizing for innovation is the need to balance exploiting existing capabilities with the pursuit of new opportunities. As previously mentioned, this concept of organizational ambidexterity captures the challenge of exploiting current capabilities and exploring new (Raisch et al, 2009). Managing this balance requires awareness of four tensions, that can be seen in Table 4.

Tension	Description
Differentiation vs. Integration	Whether innovative efforts should be conducted in distinct unit vs. if they should be mixed with all functions throughout the firm
Individual vs. organizational level	The challenge is to understand how individual capabilities for ambidexterity contribute to overall organizational ambidexterity.
Static vs. dynamic perspective	Determining whether organizations should strive for a constant balance or be prepared to shift their focus between exploitation and exploration.
Internal vs. external orientation	The tension here is between relying on internal capabilities and structures to foster ambidexterity versus leveraging external partnerships and ecosystems to complement internal efforts and access new opportunities

Table 4: Four tensions of efficient organization for innovation, based on (Raisch et al, 2009).

Different approaches to ambidexterity offer different approaches to resolving these tensions. Structural ambidexterity, where firms create dedicated units for exploration while maintaining separate units for exploitation, is particularly effective in larger organization that can afford to allocate resources across multiple projects (Chen, 2017). Meanwhile, contextual ambidexterity, where teams within firms handle both exploration and exploitation (Pugh, 1990), is more suitable for environments that are experiencing both incremental and radical innovations on a regular basis.

Whether a firm adopts a structural or contextual approach to ambidexterity, the very nature of innovation presents a double-edged sword. While urgency can create the momentum needed, it can also lead to prevention focus, where individuals become hyper-aware of the risks associated with their projects (Fredberg & Pregmark, 2022). For firms to navigate this paradox, leaders must carefully balance urgency with controlling the fear of failure. By framing ambitious goals as learning opportunities rather than performance benchmarks, organizations can transform pressure into an enabler of exploration rather than a source of stress.

2.4 Theoretical Boundaries

To support innovation and effective collaboration across departments, it is essential to understand how different professional backgrounds influence communication and coordination. Modern organizations consist of different departments with diverse sets of practices, knowledge bases, terminologies, and goals. These differences existing between departments in an organization, referred to as theoretical boundaries, separate one groups' practice from another (Star & Griesemer, 1989). According to Star and Griesemer (1989), such difficulties arise because individuals and groups possess different knowledge bases, shaping how they interpret different objects, methods, and processes.

These different interpretations can create barriers between internal departments, making mutual understanding and collaboration challenging. This is further described by Carlile (2002), highlighting how an individual's functional role and disciplinary background strongly influence how something is interpreted. These theoretical boundaries are not always problematic but can become serious obstacles for effective collaboration in an organization. This is especially evident in complex cross-organizational processes, where participants from different domains of expertise must work together despite having divergent perspectives and priorities. Overcoming these boundaries requires mechanisms that foster shared understanding and support coordinated interpretation and alignment across functions.

2.4.1 Boundary Objects

These mechanisms with the aim of bridging theoretical boundaries are grouped under the concept of boundary objects. This concept was introduced by Star and Griesemer (1989) as objects existing at the interface between different organizational departments facilitating coordination and collaboration by working as shared reference points. The definition of a boundary object is that it is "*plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites*" (Star & Griesemer, 1989, p. 393). In other words, these objects shall be able to provide a common reference point across departments, while still being flexible and adapted to the specific context of each department. This concept was further elaborated on by Carlile (2002), proposing that boundary objects support in navigating three different levels of knowledge boundaries, being syntactic, semantic, and pragmatic. In Table 5 below, these three knowledge boundaries are explained in further detail.

Boundary Type	Challenge	Role of Boundary Object
Syntactic	Differences in language, terminology, or format.	Helps translating knowledge into a common format or language that everyone can understand.
Semantic	Differences in meaning or interpretation of shared terms and concepts.	Helps clarify meaning and enabling mutual understanding of concepts.
Pragmatic	Differences in interests, priorities, or objectives.	Helps in transforming knowledge and aligning goals across different departments.

Table 5: Explanation of the three different types of knowledge boundaries.

However, this is not a simple quick fix. To effectively implement mechanisms like boundary objects and foster cross-functional collaboration, organizations must also manage the human and organizational aspects of change. Organizational change is inevitable and often a challenging process for organizations looking for continuous success in a competitive environment (Kotter, 1995). For effective change, there are models such as the one by Kotter (1995) explaining eight essential steps to manage change in organizations.

2.5 Battery production

As battery production continues to expand rapidly to meet the growing demand for electrification, understanding the complexity and challenges of this process becomes increasingly important. This section outlines the battery manufacturing process, emphasizing the role of procurement, maintenance, and organizational coordination in ensuring quality and efficiency. By providing insight into both the technical steps and the strategic considerations, the aim is to contextualize how theory translates into practice within a highly dynamic industrial environment.

2.5.1 Production process

The process of producing lithium-ion batteries is complex consisting of multiple steps spanning from the external acquisition of material to the following internal production stages: electrode manufacturing, cell assembly, and cell finishing (Plumeyer et al., 2023). Each of those production stages consists of numerous sub-processes, where high qualitative performance in each of them is crucial to manufacture reliable battery-cells with acceptable performance (Örüm Aydın et al., 2023). Therefore, the following paragraphs in this section will explain each of these steps aiming to create a complete understanding of what is required to manufacture a battery-cell. In Figure 4 below, the process steps are visualized to create an initial understanding of the steps being explained subsequently.

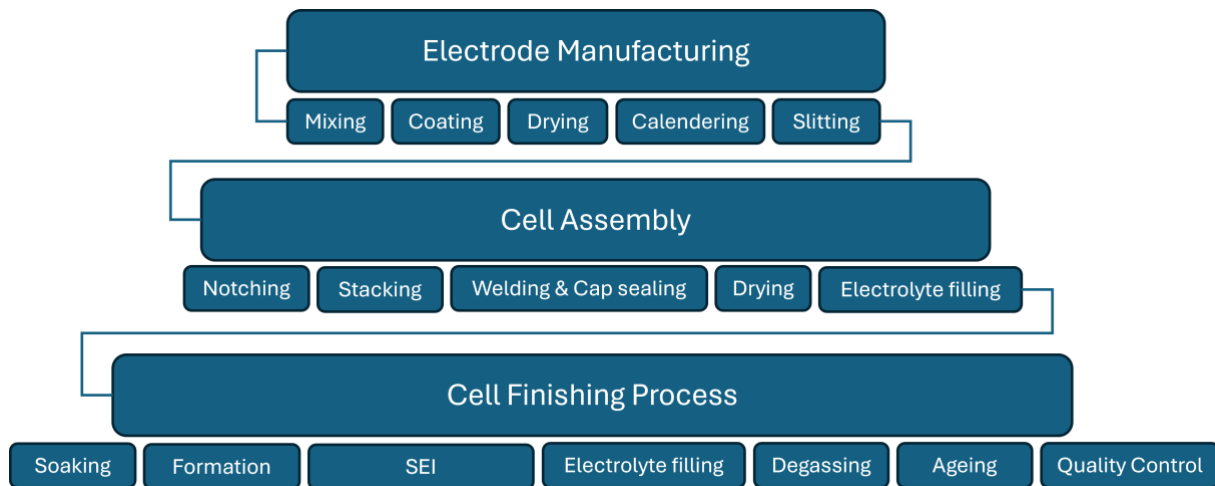


Figure 4: Graphical visualization of the battery production process

The first step for production of battery cells is the electrode production, where the initial raw material is processed to anode and cathode through several subprocesses (Plumeyer et al., 2023). The subprocesses to form the anode and cathode are mixing, coating, drying, calendering, and slitting (Liu et al., 2021; Plumeyer et al., 2023). First, the active material is mixed to a uniform slurry together with conductive additives and binding material. Followingly, this slurry is coated to both sides of two different metal foils, where aluminum is typically used for the cathodes while copper foil is the most common for anodes (Liu et al., 2021). These coated foils are then going through a strictly controlled drying process making sure solvents are evaporated carefully to prevent thermal stress, which could have negative impacts on the electrodes (Liu et al., 2021).

Once the electrode material has dried properly it undergoes a calendering process which compresses it between heated rollers, thus decreasing its thickness (Örüm Aydın et al., 2023). The purpose of making the electrode material denser is to improve the bonding between active materials and the substrate, which have positive effects by improving the electrodes' stability and energy storage capacity (Liu et al., 2021). Finally, in the slitting process, the electrode sheet is cut into the desired dimensions (Örüm Aydın et al., 2023) and subsequently sent to vacuum dryers to remove remaining moisture and minimize the risk for corrosion (Liu et al., 2021).

Followingly, these electrodes are assembled into the final battery cells through the cell assembly process (Plumeyer et al., 2023). The first step is notching, where the electrode sheets prepared in the calendering process are cut once again, but to the required dimensions for the specific battery cells, including the formation of tabs that later will serve as connections points for the electrodes (Örüm Aydın et al., 2023). Subsequently, the electrode layers are assembled into a structured stack. Once they have been stacked, they are first secured with tape to prevent misalignment and then heat-pressed whereas the final quality is checked by a thickness measurement. In this stage, further tests are being made to control the electric insulation of the battery stack. This is done by a Hi-Pot test where the cell stack receives high

voltage currents for a specified time, while the leakage current is measured to evaluate whether the electric insulation of the stack is within the required tolerances or not (Örüm Aydın et al., 2023).

The next step is the welding and cap sealing process, where the anode and cathode tabs first are joined together followed by welding and securing of the cap (Örüm Aydın et al., 2023). To guarantee proper insulation, this cap is wrapped with tape, followed by an additional Hi-Pot test to verify its electric insulation properties. Followingly, the stack is wrapped in tape for electric insulation and then inserted into the battery cell housing, which is sealed by welding creating a robust structure. This enclosure warrants the mechanical stability of the battery and provide protection for its internal components (Liu et al., 2021).

The final steps in the cell assembly consist of another drying process followed by the electrolyte filling. Both process steps are carried out in clean and dry room conditions, where the number of particles per cubic meter is measured and controlled to maintain quality (Örüm Aydın et al., 2023). Moreover, the drying process is carried out using vacuum to remove moisture and solvents that could create unwanted chemical reactions and electrolyte degradation. Once this drying process is finished, the electrolyte is added into the enclosure, which then is sealed, marking the final stage of the cell assembly process (Liu et al., 2021).

The final main step in battery production is the cell finishing process consisting of numerous sub-processes such as high-temperature soaking, formation charging, SEI development, electrolyte filling, degassing, ageing, and quality control (Liu et al., 2021; Plumeyer et al., 2023;). First, the filled enclosures undergo a high temperature soaking at approximately 45 degrees Celsius, decreasing the electrolytes' viscosity helping it to spread more evenly in the cell structure (Liu et al., 2021). This phase ensures that the subsequent electrochemical reactions occur in a great environment, minimizing future inconsistencies in the cell performance (Örüm Aydın et al., 2023). The duration of the soaking process varies depending on factors such as the cell chemistry, format and its size all impacting the required time for achieving a homogeneous spread of electrolytes (Plumeyer et al., 2023).

Subsequently, the cell is charged for the first time starting the electrochemical activation of the cell by forming the solid electrolyte interphase (SEI) (Örüm Aydın et al., 2023). This SEI is characterized by a layer being formed at the interface between the anode and the electrolyte, preventing unwanted reactions between them from occurring, and is thereby crucial in ensuring a long-term stability of the cell itself (Liu et al., 2021). The first charge cycle is started at a low voltage to protect the copper current collector from corrosion, which then is gradually increased creating a more stable SEI over time (Plumeyer et al., 2023). This formation of the SEI layer, traditionally require a minimum of two full cycles of charge-discharge at low rates making the total process take up to 48 hours (Örüm Aydın et al., 2023).

During the charge-discharge cycles in the SEI-formation some electrolyte components are reduced in the cells, which often is compensated by additional electrolyte fillings to restore the electrolyte volumes (Liu et al., 2021). Followingly the final sealing is completed via

welding, preventing external moisture to affect the battery cell, and thus maintaining the internal chemical composition (Örüm Aydın et al., 2023). Moreover, some of the electrolyte components decompose during the process, releasing gases accumulating in the battery cell (Liu et al., 2021). If these are left unvented numerous negative consequences impacting the cell integrity such as electrolyte displacement, pressure buildup and internal mechanical stress can occur (Plumeyer et al., 2023). Therefore, a degassing process to release the trapped gases is usually implemented for safety and quality control purposes (Örüm Aydın et al., 2023).

After degassing, the battery cells undergo the aging process, with the aim to stabilize the internal chemical reactions and verify its long-term performance (Örüm Aydın et al., 2023). In this stage, the cells are stored in conditions of both high and room temperature facilitating the electrolyte redistribution and improving the SEI (Liu et al., 2021; Plumeyer et al., 2023). This process is typically the largest bottleneck in production taking somewhere between 8 and 36 days depending on the cell format (Örüm Aydın et al., 2023). During this stage the open-circuit-voltage is measured to determine the battery cells' self-discharge rates where to high rates might indicate defects in terms of internal short circuits or electrode degradation (Liu et al., 2021). Finally, different currents and voltages are tested at the batteries, simulating real operating conditions, thus detecting potential defects before going being distributed to customers (Plumeyer et al., 2023).

Finally, when the aging process is complete, the battery cells go through some final quality assessments evaluating the performance, thickness, and charge retention of the cells. Based on this evaluation, the approved battery cells are sorted into different quality grades depending on their characteristics (Liu et al., 2021). Once the battery cells are sorted based on their quality levels, they are ready to be sold and distributed to the customers.

2.5.2 Validation of Production

While understanding the steps involved in battery production, it is equally important to ensure that these processes work as planned. In modern manufacturing, and especially in high technology industries like battery production, it is essential to validate both the equipment and the production processes before launching full-scale operations. The validation of production equipment is necessary to ensure that the equipment functions as planned, while the validation of production processes is needed to guarantee the capability of delivering products meeting the required specifications.

The validation of the production equipment is often managed by a set of tests being conducted all the way from the suppliers' site until it is in full-scale operation at the buyer. First, a factory acceptance test (FAT) is carried out at the manufacturers' site to confirm that the equipment meets specified requirement and is free from defects hindering it from operating correctly (International Electrotechnical Commission [IEC], 2024). It usually includes a collaboration between manufacturers and buyers jointly validating the custom-built equipment by assessing the integration and interoperability of different components (Krüger et al., 2024). This serves an important purpose since early identification of issues during the FAT significantly reduces

the costs and risks compared to identifying faults after delivery or during operation (Krüger et al., 2024). However, it is not sufficient to only conduct tests at the manufacturers' site since environmental specific factors at the suppliers' site such as humidity, temperature and cleanliness need to be evaluated at the location where the equipment will operate.

To ensure the functionality of the equipment at the location of installation, some additional tests are carried out. During a Site Acceptance Test (SAT), the delivered equipment is inspected to verify that it complies with the predetermined specifications and standards (IEC, 2024). Subsequently, additional tests in form of a Site Integration Test (SIT) are conducted. Since a production line, consists of many different processes, the production equipment must be integrated into a functioning system, where all parts can work together. Therefore, the SIT is according to IEC (2024), carried out with the purpose of demonstrating that the different components can be merged and operated together while meeting the set specifications.

Furthermore, the production processes must be validated to ensure that the setup is capable to manufacture products according to the set requirements. The development of production setups with innovative technologies typically undergoes four different phases in terms of a research phase, pilot phase, ramp-up phase until the final stage of large-scale production is possible (Küpper et al., 2025). This is further explained by Liheng et al. (2017) linking Manufacturing Readiness Levels (MRL), reflecting how ready a manufacturing process is to cost-effectively and reliably produce new technology products at scale, to the four different phases. In these MRLs, companies must prove sufficient manufacturing capabilities before moving over to the higher level to guarantee high-quality production.

In the research phase, new technologies and concepts are tested in a laboratory setting to assess its benefits and applicability (Küpper et al., 2025). In relation to the MRLs, the focus is to develop manufacturing proof of concepts and demonstrate that prototypes can be produced in the laboratory environment (Liheng et al., 2017). Furthermore, in the pilot-phase prototype components and systems are manufactured at small scale in a real production environment (Küpper et al., 2025). Moving over to the ramp-up phase, the MRLs explains that it is about proving that real components and systems can be produced in an actual production environment, but at lower volumes. This stage is implemented incrementally with much focus on process optimizations and solving challenges until large-scale production is achievable. Finally, in the large-scale deployment it is about proving that full capacity production is possible while meeting all requirements (Küpper et al., 2025; Liheng et al., 2017).

2.5.3 Challenges in Battery Production

Even when production lines and equipment have been validated, manufacturers in the battery production industry must still manage a range of complex challenges. Therefore, this section describes key issues affecting the industry, beginning with the market imbalance, followed by raw-material dependencies and the impact of rapid technological development. Furthermore, some economic and operational challenges faced by manufacturers in the industry are explained. Table 5 below provides an overview of the key challenges in battery production,

where each area is briefly summarized corresponding to the sections below, where these are further explained in detail.

Area	Main challenges
Market Imbalance	Growth of demand not aligned with initial projections, risk of overcapacity/underutilized factories
Raw-Material Dependency	Reliance on critical materials from geographically concentrated areas. Risk of future shortages and increasing price volatility.
Technological Development	Rapid development of chemistries. Risk of lock-in costs due to infrastructure investments, while long-development cycles force long-term planning in an uncertain environment.
Cost Structure	Thin profit margins and high material costs (75% of total) and cost disadvantages compared to Asian producers.
Scaling and Quality Control	High scrap rates during ramp-up (90%), minimal tolerances requiring extreme precision to detect defects.

Table 5: Summary of Key Challenges in Battery Production

Although the market demand for batteries is increasing, the actual market growth is not completely aligned with earlier projections. Instead, Küpper et al. (2025) points out how the global cell production capacity may significantly exceed the demand for the coming five years, where actors in the market face risks of overcapacity. This potential mismatch between supply and demand can lead to gigafactories facing low utilization rates, causing financial strains and forcing manufacturers to rethink coming expansion plans and cost structures (Roland Berger, 2024). One reason for this mismatch is that the adoption of battery electric vehicles has been slower than expected, where many consumers are shifting focus towards hybrids, thus reducing the demand for high-capacity battery production (Roland Berger, 2024).

Closely tied to this market imbalance are the material dependencies characterizing battery production. This battery-producing industry is highly dependent on raw material coming from geographical concentrated regions, exposing manufacturers to supply chain risks and potential price fluctuations (Örüm Aydın et al., 2023). For example, lithium, nickel, and graphite are all essential material for lithium-ion-batteries, which are sourced from a few key areas, such as the Democratic Republic of Congo, China, and Chile (Örüm Aydın et al., 2023). Adding to this, studies have shown that current supply levels of these critical materials at highest only meet 35% of the projected demand for 2050 making future shortages likely (Krishnan et al., 2024).

In parallel with these sourcing challenges, another complicating factor in battery production is the rapid technological development of battery chemistries. The highly innovative industry force manufacturers to continuously evaluate new technologies to remain competitive (Roland Berger, 2024). Adopting mature technologies can according to (Küpper et al., 2025) reduce costs by approximately five percentage points, while technologies expected to mature in five years could offer savings of further 10-15 percentage points. Therefore, the industry is

characterized with a highly dynamic, and thus uncertain, environment where the dominating chemistry a few years ahead remains unclear (Küpper et al., 2025).

This can create lock-in costs for the manufactures investing in infrastructure with the risk of becoming obsolete, since a changed focus on battery chemistry often require replacement of around 50% of current production equipment (Küpper et al., 2025). In addition, long development cycles for new battery production technologies, often requiring several years from early lab-testing to industrial scale, further complicates the process (Örüm Aydın et al., 2023). Thus, while the rapid technological advancement is a key to improve performance, it also introduces significant complexity in investment planning and infrastructure flexibility.

In addition to these strategic uncertainties, the economic aspect of production adds further pressure on manufacturers in the battery industry. The manufacturers operate with extremely thin profit margins of only a few percentages, making it essential to optimize operations and minimize its inherent waste (Attia et al., 2025). One of the primary reasons for this is that material costs currently account for approximately 75% of the total production costs, and these cost pressures will only increase as raw material prices continue to rise (Örüm Aydın et al., 2023). From a competitive perspective, there are huge regional differences related to expenses in the battery production industry. Due to differences in labor, energy, and capital expenditures the cost per cell produced in China are significantly lower compared to the cells produced in high-cost regions such as Europe and the US (Küpper et al., 2025). Consequently, this cost disadvantage force players in these high-cost-regions to identify efficiency improvements through cost-saving innovations, automation, and process optimization (Küpper et al., 2025).

One major driver of costs in the industry is due to the challenges of scaling from lab-prototypes to full-industrial scale manufacturing. In this ramp-up phase, scrap rates represent a major source of expenses, where scrap rates can reach up to 90% only stabilizing after extensive process optimizations (Attia et al., 2025). At full industrial scale, gigafactories produce up to 70 battery cells per second, thus requiring extreme precision to prevent defects and to maintain consistency of production (Attia et al., 2025). This is a significant challenge since minimal defects in the span of 10-100 micrometers can cause failures of catastrophic magnitude (Attia et al., 2025). Some of these defects might not according to (Attia et al., 2025) be immediately identified and may show up after months or years of use, thus making quality control essential. During the high-speed production, the high throughput rates come with the risk of increased escape rates leading to recalls and warranty claims (Attia et al., 2025), which can cause significant financial losses due to the high material-costs (Örüm Aydın et al., 2023).

3 Methodology

This paper outlines the research methodology employed in the study. It covers the use of abductive reasoning, the selected research design, data collection and analysis methods, the approach to literature study, and the measures taken to ensure quality assurance.

3.1 Abductive reasoning

When conducting research, researchers typically adopt one of three approaches: deductive, inductive, or abductive (Bell et al, 2022). A deductive approach begins with a pre-established hypothesis or theory that the researchers aim to, through observation and/or experimentation, either confirm or reject. In contrast, an inductive approach to research does not rely on any set theories. Instead, this approach aims to use the researcher's observations and data collection from a certain field to form new theories. Lastly, an abductive approach begins with observations and aims to find the most likely explanation for them. This approach is often used to develop theories and hypothesis based on the best available evidence. This mode of reasoning has grown in popularity in business research (Bell et al, 2022) and is the approach this paper used. This paper used abductive reasoning because it helps connect observations with the best possible explanation, making it useful for exploring new topics in business research.

3.2 Research design

The research design for this master's thesis was designed to explore how maintenance can be incorporated effectively in the strategic purchasing of production equipment within the battery industry. This study employed a sequential design of a case study, where the answers to the first two research questions assist in answering the third one. Sequential designs are particularly useful in qualitative research when each phase is built upon insights gained in the previous phase (Bell & Bryman, 2011). Therefore, a qualitative approach was used to provide in-depth insights into the processes and implications at Northvolt. In addition to having a sequential research design, a qualitative approach was selected due to its suitability in investigating both organizational practices and individual perspectives (Patel & Davidson, 2011). This aligns with the study's aim to understand organizational practices from different individual perspectives. The sequential design consisted of three phases, where the first two were carried out with some overlap. Further explanations of the phases will be described in depth in the coming chapters, for a short visualization of the research design, see Figure 5.

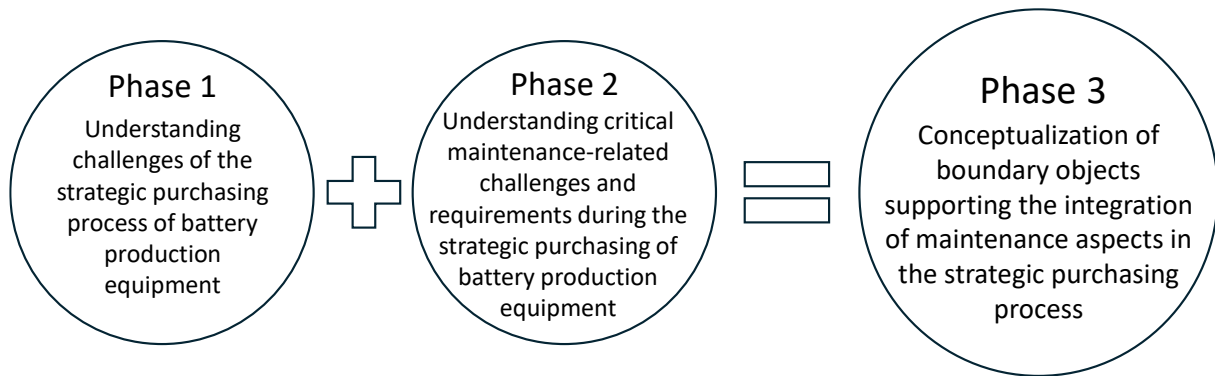


Figure 5: Graphical visualization of the research design

3.2.1 Phase one – Understanding challenges in the purchasing process

The initial phase of this paper focused specifically on the first research question. Firstly, the aim was to create a solid understanding of the current process for strategic purchasing of battery production equipment at Northvolt. Secondly, the challenges of the strategic purchasing process and the employed mitigation strategies were discussed and documented in a table format. The approach to doing this was based on a combination of theoretical literature reviews and gathering of empirical data from semi-structured interviews with individuals at Northvolt’s purchasing department. In this phase, six interviews were conducted with a diverse set of senior and junior individuals within the purchasing department. The titles of the respondents and the duration of each interview can be seen in Table 6.

Individual	Title	Duration
Respondent 1	Purchasing Director	47 min
Respondent 2	Purchasing Manager	64 min
Respondent 3	Head of Procurement - Process Equipment	35 min
Respondent 4	Process Engineer	40 min
Respondent 5	Category Specialist	50 min
Respondent 6	Category Specialist	42 min

Table 6: List of interviewee respondents for phase 1

The main purpose of the theoretical literature review was to build a solid foundation of knowledge prior to the interviews. Partly to create efficient interview guides aligning with the overarching purpose of the study and ensuring useful information to the final results, see appendix A for the interview guide of this phase. However, as an interviewee in semi-structured interviews it is also important to have solid knowledge of the concepts since correct interpretation of answers is fundamental to redirect the discussions into areas of interest for the study. Therefore, being prepared and knowledgeable in the area prior to the interviews can enrich the answers and further elevate the end results of the report. Based on the interview guides created from the literature review, semi-structured interviews were held with relevant individuals in the purchasing department of Northvolt. To ensure the relevance of the interview participants the supervisor at the case company was involved in this process.

3.2.2 Phase two – Identifying maintenance requirements for the purchasing process

In the second phase of this study the focus was to understand what maintenance-related challenges and requirements are critical to address during the strategic procurement of battery production equipment. Similarly, to the first phase, this part employed a combination of literature review and semi-structured interviews. Here, the intention was that findings from the empirical results from the interviews would contribute to understanding what parameters are crucial to consider from a maintenance point of view for sourcing of new production equipment.

The literature review was conducted to ensure proper preparations prior to the interviews to tailor an efficient interview guide. For the interview guide for this phase, see appendix B. After the literature review, semi-structured interviews were conducted with individuals at the maintenance department at Northvolt. Just as for the first phase, the supervisor at the case company was involved to identify adequate participants for the interviews. The titles of the respondents and duration of each interview can be seen in Table 7.

Individual	Title	Duration
Respondent 7	Senior Manager	46 min
Respondent 8	Workshop Manager	52 min
Respondent 9	CE Specialist	41 min
Respondent 10	Maintenance Engineer	38 min
Respondent 11	Senior Maintenance Engineer	57 min
Respondent 12	Maintenance Engineer	37 min

Table 7: List of interviewee respondents for phase 2

The overall findings from this phase summarized what different aspects that have been found crucial to consider in the purchasing process from a maintenance perspective. Together with results from phase 1, this data served as the main input to the final phase.

3.2.3 Phase three – Conceptualization of boundary objects supporting the integration of maintenance aspects in the strategic purchasing process

This final phase presents the results connected to the primary aim of this study. By using the crucial aspects found in the first two phases of the study, boundary objects that bridge the gap between maintenance and strategic procurement of battery production equipment were designed. By the use of extensive analysis, the boundary objects were designed with consideration to the identified challenges in the first two phases. The final outcome of this phase was the creation of an integrated system of boundary objects, aiming to mitigate the identified challenges while facilitating an effective integration of the lessons learned from the first two phases, into the strategic procurement process of battery production equipment.

3.3 Data collection

The individual perspectives were primarily collected through semi-structured interviews with the procurement- and maintenance departments at Northvolt. Semi-structured interviews allowed for a flexible yet guided way of collecting data from the participants (Bell & Bryman, 2011). These semi-structured interviews were guided through the usage of an interview guide, where a set of prompts or questions were formulated beforehand. These interview guides differed depending on who was being interviewed, why they were being interviewed, and at what point in the timeline they were being interviewed. To ensure the accuracy of data collection, thorough notes were taken in combination with recording and transcribing of the interviews. The semi-structured interviews served as the basis for answering the research questions.

In this master's thesis, all interviews were conducted online. This is due to the limitations of the paper that limits the access to physical interviews. Conducting interviews online introduces both opportunities and challenges. Online interviews enable logistical advantages such as reduced travel cost and less time spent traveling. Moreover, they are also easier to schedule and reschedule due to eliminating travel, which increases the flexibility of them (Bell et al, 2022). One potential downside of online interviews is the reduced ability to capture non-verbal cues that would be possible if the interviews were conducted face-to-face. To mitigate the challenge of this, clear interview guides with open-ended questions were formulated to encourage the participants to communicate openly. In this study, the interviewees could be located in multiple locations, making online interviews the best option.

A purposive sampling strategy were employed to identify participants who are directly involved in or knowledgeable about the purchasing and maintenance processes. Purposive sampling is a non-probability sampling where participants are selected based on their relevance and knowledge about the research objects (Bell & Bryman, 2011). Additionally, snowball sampling, a form of convenience sampling where the interview participants assist in finding additional participants, they deem to be interesting (Bell & Bryman, 2011), was used. Using a purposive sampling strategy in combination with a snowball sampling strategy ensures that the correct people are being interviewed for what the purpose of the study is.

3.4 Data Analysis

In the first phase, interviews were designed to identify challenges in the procurement process, the mitigation strategies employed as a response and their operational impacts. In the second phase, the focus shift toward identifying challenges within the maintenance function along with their operational consequences. In both phases, a purposive sampling approach was employed targeting respondents with relevant operational and managerial insights. The data collection continued until a saturation point was reached, defined as the point where now new substantial themes or insights emerged from additional interviews (Bell & Bryman, 2011).

Each interview was audio-recorded with the informed consent of participants and subsequently transcribed to ensure a comprehensive and trustworthy representation of the data. Following the transcription, an initial phase of open coding was independently conducted by both researchers. No predefined categories were created. Instead, emergent challenges, mitigation actions, and consequences were identified directly from the transcriptions. This coding process enhanced the analytical depth by allowing novel themes to be identified without being imposed to theoretical constraints.

To further enhance the credibility and dependability of the analysis, the concept of investigator triangulation was applied (Patel & Davidson, 2011). After completing the independent codings for each interview, both researchers engaged in collaborative discussions to compare findings, address discrepancies, and iteratively group findings into broader thematic categories. This process was repeated after each interview and followed the principles of a constant comparative method (Bell & Bryman, 2011), where each new finding was compared against existing findings and categories to update and expand the thematic framework.

The third and final phase of the analysis aimed to move beyond identification of challenges by incorporating the findings into a conceptual system of boundary objects aiming to bridge barriers between procurement and maintenance functions. This phase adopted an abductive research approach, where empirical insights from the first two phases, were combined with theoretical frameworks, to guide the creation of practically relevant boundary objects. In particular, the framework of Carlile (2002) on knowledge boundaries, highlighting the need to address syntactic, semantic, and pragmatic differences between organizational departments guided this process.

This phase was characterized by an exploratory and collaborative dialogue, where the researchers revisited the identified challenges discussing how each could be mitigated through appropriate boundary objects. The goals were to design an integrated system, where different types of boundary objects, including roles, formal processes, documents, and forums for dialogue and continuous improvement, could interact and reinforce each other. By combining the empirical observations with theoretical insights through abductive reasoning, the study produced a system of boundary objects intended to facilitate a deeper integration between procurement and maintenance functions.

3.5 Literature study

Throughout the study, an iterative literature study was conducted. This part was aligned with the three phases of the study, where the initial part focused on purchasing and the subsequent one on maintenance. For the final phase, the literature review revolved around concepts of strategic procurement, maintenance, battery production, change management, and theoretical boundaries, ensuring the creation of actionable steps through the design of boundary objects supporting a smooth integration of maintenance considerations in the strategic procurement process. Furthermore, areas of interest were discovered through data

analysis of information collected from the semi-structured interviews. As these themes emerged, relevant academic and industry literature was studied to deepen the understanding of them. This approach ensured that the literature study had the correct theoretical foundation for its use.

Keywords: Battery Production Challenges, Battery Production Equipment, Boundary Objects Purchasing, Maintenance, Strategic Procurement, Theoretical boundaries.

3.6 Quality assurance

Ensuring the reliability and validity of the study is essential for maintaining the credibility and transferability of the findings in this study. While qualitative research does not seek to produce identical results under all circumstances, measures were taken to ensure that the process is trustworthy. The reliability of a study refers to whether the results derived from the study can be repeated. In qualitative research, reliability can be broken down to external reliability, indicating the degree to which the study can be replicated, and internal reliability referring to the extent to which researchers within the studied area agree on the interpretation of the data (Patel & Davidson, 2011).

To ensure the external reliability of the data, all research decisions were documented along with interview guides and transcripts/notes of the semi-structured interviews. This made it possible to see how the results of the study were derived and that the process was done in a correct fashion. Furthermore, to ensure internal reliability, notes derived from the semi-structured interviews were compared with relevant industry documents and prior research within the field. Additionally, external researchers in the form of the Examiner and Supervisor of this paper were involved to ensure internal reliability. Their input will be used to validate the interpretations made from the data.

Finally, the validity of the study refers to the extent to which the findings accurately represent the phenomena being studied and align with the research objectives (Bell & Bryman, 2011). To ensure the validity of the study, a thorough review of existing literature was conducted. Also, the report contains detailed documentation of the research process, including research questions. To make the study repeatable, the research questions are incorporated in the report, ensuring that others can conduct similar research.

3.7 Usage of generative AI tools

This report has been refined with the help of generative AI tools to improve the clarity and flow of the original text. All the ideas, analysis, and written material originate from the report's authors, with AI assistance used solely to edit language and enhance readability without contributing new content. More specifically, ChatGPT was utilized occasionally to get language improvement suggestions for certain sections, which were then manually edited without assistance by considering the provided feedback.

4 Results

This section presents the results from the first two phases of the study, based on empirical data gathered through semi-structured interviews with individuals from various departments at Northvolt. First, the procurement process is mapped out, highlighting key challenges and corresponding mitigation strategies. Subsequently, the focus shifts to the maintenance perspective of strategic purchasing, outlining its specific challenges and requirements.

4.1 Procurement Process

This part of the result section aims to describe the current state of the strategic purchasing process for battery production equipment at Northvolt. Information used for this is based on empirical data retrieved through interviews with individuals working within purchasing and process engineering. The following parts of this section will be divided into subsections based on the different steps of the process, see full process in Figure 6.



Figure 6: Full procurement process

4.1.1 Market Research

Upon review of the strategic sourcing process for battery production equipment, it aligns well with linear purchasing model. The process includes the general steps, all the way from setting specifications, evaluating suppliers, awarding contracts, until following up the final performance. However, in addition to these steps triggered only when the procurement process of new equipment starts, there are also ongoing day-to-day activities carried out by the purchasing teams that lay the foundation for future acquisition processes.

Each team manages a product category and develops tailored strategies aligned with overall procurement goals, guiding staff on how to operate within each category. In the day-to-day activities, purchasers have the responsibility to continuously conduct market research within their assigned category. This involves monitoring market trends, pricing, and supplier capabilities within the specific segment. By ensuring a meticulous scouting of the market, forthcoming activities are facilitated, since there are already broad lists of potential suppliers established. Finally, the information gathered through market research also serves as an important input to iteratively adapt the category strategies in line with the macro-environmental context.

4.1.2 Identifying and Setting Specifications

Subsequently, the needs of novel equipment are identified by engineers and process teams in the firm. Due to high customization of battery cells, final product requirements primarily determine the equipment specifications. In discussion with customers, product specifications are translated by process-engineers into process requirements, ensuring the desired product can be produced at site and meet operational parameters. These specifications are technical with a high level of detail, outlining the desired equipment characteristics.

However, in parallel the procurement team use their market intelligence together with more broad functional specifications, preparing an extensive list of suppliers relevant for the upcoming selection process. After iterative discussions with internal stakeholders such as process engineers, maintenance-staff and personnel in operations, the requirements are clarified making the specifications more detailed as the process progress. These technical specifications are tailored to the equipment being purchased, but in addition there are general technical specifications at the firm incorporated in all new equipment purchases. While the equipment-tailored specifications focus on its performance, the general specifications emphasize safety aspects and maintenance considerations such as distance requirement for accessibility. With these specifications prepared, the procurement process continues with different steps to select a suitable supplier.

4.1.3 Supplier Evaluation and Selection

The process of selecting a supplier aligned with the set specifications begins with a request for information (RFI). This serves as an initial outreach to assess supplier capabilities and determine if they are viable candidates for the specific acquisition process. Typically, this RFI is sent to 10-15 suppliers, though this varies based on market availability, especially in battery production equipment, where options are often limited. Information asked in this step is mostly related to references of past projects and simple checks of their technical capabilities. This initial assessment helps narrow down the number of suppliers to around five shortlisted candidates, though this number also may vary depending on market availability.

For shortlisted suppliers, a Request for Quotation (RFQ) process is initiated to further evaluate their capabilities in relation to technical specifications and commercial aspects. For example, suppliers are asked to submit documents such as technical solutions, drawings, process diagrams and further references from previous projects demonstrating their capabilities. Additionally, structured workshops may be held with the suppliers to clarify technical solutions and refine the offers. When the supplier capabilities and required technologies become, the scope of the purchase and required collaboration might vary. For instance, more complex, next generation-equipment is often co-developed under Joint-Development Agreements (JDA), while less complex, established equipment may use traditional contracts. Alongside the technical documents in this part, price and contract negotiations are started to assess commercial feasibility with each supplier.

When all this information is gathered from the shortlisted suppliers, they are evaluated against each other based on different criteria. This is a cross-functional process where different departments are responsible for evaluating each offer in their area of expertise. For example, the first category of criteria contains technological aspects in how well the offering meets technical requirements. Within this group of criteria, the process engineers are responsible for evaluating the offerings and set quantitative scores for each criterion leading to a final score for each supplier with regards to the technical side. The same procedure is repeated for five additional categories. Procurement assesses commercial aspects, such as pricing, TCO, warranties, and logistics. Quality management is evaluated through audits, considering practices and ISO/CE certifications. Sustainability is assessed through emissions data and certifications. Furthermore, financial stability of each supplier is reviewed to mitigate risk. Finally, soft factors such as communication, collaboration, and shared values are also scored to ensure a well-functioning relationship.

Once all areas are scored, and each category is weighted, total scores are calculated to compare suppliers overall ranking. The highest scoring supplier is then often identified as the most suitable option. This outcome is then further reviewed internally, often by a sourcing council consisting of top management and representatives from departments affected by the decision. These discussions incorporate multiple perspectives to support a well-grounded final decision.

4.1.4 Contracting and Implementation

Having selected the supplier, the final details in the contract negotiations are completed. Many of these aspects are discussed throughout the RFQ-process, but some details remain to be settled, such as final milestones, delivery schedules, warranties, and payment terms. Payments for these costly investments are often milestone based, from completed factory tests at the supplier, to the final ramp up of production at the customer site. In addition, details regarding service level-agreements (SLA), spare parts, and clauses for accepted future modifications are finalized at this stage. Once agreed, production begins while the Northvolt conducts supplier visits, field expediting, and carry out tests to ensure the project remains within the desired scope. Equipment from suppliers is also often tested on a small scale at the R&D facility, before being implemented at full scale in the production facilities. Finally, once the equipment passes all tests, it is integrated into production, marking the end of the procurement process.

4.2 Key Purchasing Challenges and Mitigation Strategies

The procurement process of battery production equipment involves challenges that span across multiple aspects of procurement such as supplier selection, maintenance integration, and managing changes, each requiring specific mitigation strategies. This section is structured into six key areas that represent the most critical challenges identified through interviews with participants directly involved in the day-to-day operations of procurement. These are: 1) setting specifications, 2) supplier dependency and regional trade-offs, 3) evaluation and

supplier selection, 4) integration of maintenance perspective, 5) short-term cost focus, and 6) managing changes and flexibility in procurement. Each key area will present the primary challenge, followed by the strategies implemented to mitigate them. To further enhance clarity, each key area will conclude with a summarizing table including the key challenges along with corresponding mitigation strategies. This approach provides insights that can be applied by other battery producers facing similar challenges. For a quick overview of the identified challenges, see Figure 7.

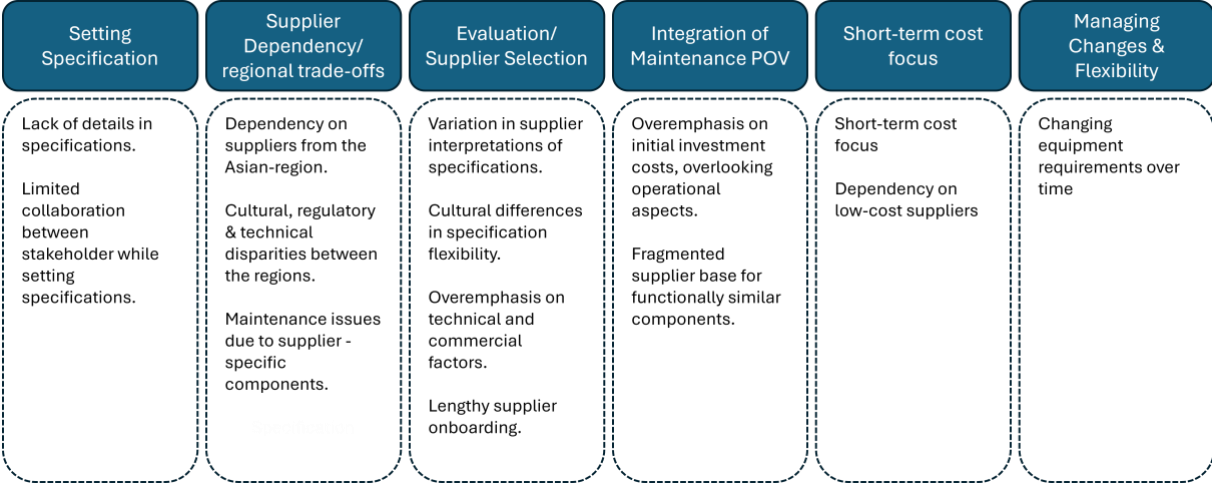


Figure 7: Challenges identified in the procurement process of battery production equipment

4.2.1 Setting specifications

Defining clear and precise specifications is critical in a successful procurement process of a complex and technical product such as battery production equipment. However, the initial approach at Northvolt did not involve extensive specifications, because of limited experience in an emerging industry. Interviews revealed that competitors’ specifications were considerably more rigorous. This gap was especially illustrated by one of the respondents from the purchasing team with the following quote: *“If you compare us to our competitors, they might have had a specification that was up to 1000 pages long, while ours only was around 20 pages in total”*. As a result, specifications often lacked sufficient detail, making it difficult to compare suppliers and evaluate which supplier meets their needs. The absence of clear specifications made the battery production equipment behave in ways not anticipated when purchased, leading to significantly higher costs than originally thought.

Another key issue was the lack of collaboration between key internal stakeholders while setting the specifications. Initially, specifications were primarily defined by the engineers and the procurement team. This resulted in maintenance experiencing difficulties while servicing the battery production equipment. These difficulties included servicing hard-to-reach areas and machines with non-standard parts, with little to no information on how to service them or where to purchase a new part.

To improve the procurement process and mitigate the challenges caused by insufficient specifications, Northvolt has taken several steps to enhance its approach. A mitigation strategy to setting more structured specifications was to develop a more detailed and, to the extent possible, standardized way of setting specifications. By having a more rigorous process of setting specifications, Northvolt has significantly improved its ability to compare suppliers and assess which ones best meet their needs.

4.2.2 Supplier dependency and regional trade-offs

The battery industry and its supply chains are dominated by Asian firms, making the expertise concentrated in that region. This creates a dependency where European battery producers often must collaborate with those players to obtain the required expertise for setting up battery production facilities in Europe. Furthermore, this expertise combined with other factors such as lower labor costs, and excessive access to important raw materials make Asian suppliers the most cost-efficient alternative. This is a challenge encountered by the sourcing department at Northvolt, where these factors created a dependency on suppliers from the Asian region.

Although cheaper alternatives and greater expertise might sound unproblematic, the dependency on this region consequently led to some negative effects. For example, there are some cultural disparities between the regions of Europe and Asia, being evident in multiple areas during the sourcing process. First, regulatory issues were common since many suppliers did not use CE-certified components, which is a legal requirement in Europe. This made the sourcing process even more complex and lengthy, having to convince and help the suppliers achieving CE-certifications for their components. A second challenge raised were closely related to this, but even broader. The differences in technical standards between Asian and European suppliers, where CE-certification is a part, caused compatibility issues in equipment leading to both delays and increased costs. Third and final for the cultural disparities, the expectations regarding type of specifications clearly differed among the actors. For instance, during the interviews it became clear that Northvolt and European actors preferred using technical specifications, while the Asian suppliers were used to receiving a drawing presenting exactly how the production equipment should be manufactured.

Furthermore, challenges related to maintaining the production equipment purchased from Asian suppliers was also experienced. Some early procurement decisions did not consider long-term serviceability, which resulted in suppliers including region-specific components that were difficult to source locally when needed for spare-parts. One interviewee from the purchasing team described the following: *“Initially, we sourced many machines from Asia including components that were not available in Europe. This created huge problems from a maintenance perspective making it challenging to acquire spare parts when needed”*. Consequently, once disruptions for spare-parts occurred in the supply chain it led to major delays because of the long distance to these suppliers, causing high costs due to production

stoppages. In addition, the early contracts had very inflexible service agreements with limited on-site support complicating maintenance and making it even more costly.

Although, the Asian suppliers of battery production equipment provided expertise and solutions with low initial investment costs, challenges faced due to cultural disparities made Northvolt re-evaluate their sourcing approach. Instead, they made a strategic shift from purely cost-driven sourcing focusing on Asian suppliers, to a more risk-balanced approach, also including European suppliers with higher initial investment requirements and by this creating a more resilient supply chain. The challenges for this part along with mitigation strategies are visualized below in Table 8.

Challenge	Mitigation	Impact
High dependency on Asian suppliers due to cost-efficiency and high expertise, leading to supply chain risks in event of disruptions.	Diversify supplier base by considering local/regional alternatives to reduce dependency.	Greater supply chain resilience and reduced risk exposure while improving strategic sourcing.
Regulatory, technical, and cultural disparities between buyer and supplier.	Establishing clear standards and expectations when initiating the relationship to enhance supplier collaboration and reduce risks of misunderstandings.	Smother procurement process with fewer disparities by establishing common expectations and ways of working when establishing the relation.
Long-term maintenance issues due to supplier-specific components.	Prioritize suppliers offering more globally available components.	Lower operational costs, improved parts availability, improved maintenance efficiency and reduced downtime risks.

Table 8: Summary of challenges, mitigation strategies, and their impact for supplier dependency and regional trade-offs

4.2.3 Evaluation and supplier selection

The process of evaluating and selecting suppliers for battery production equipment is complex, requiring extensive market research and careful consideration of, technical, commercial, and other critical factors. One challenge that purchasing respondents frequently mentioned was the variability in how suppliers interpret specifications, making direct comparisons difficult. Here, the physical location of suppliers also seems to drive cultural differences in how these specifications should be interpreted, adding flame to the fire. Since battery production equipment is typically tailored to specific processes rather than being an off-the-shelf product, the evaluation process needs to be extensive, and the supplier needs to have a certain level of flexibility.

The evaluation processes traditionally involved evaluating the technical and commercial criteria of suppliers. However, a notable shortcoming in early supplier selection processes was

the overemphasis on these criteria and overlooking “soft” factors such as supplier communication style, cultural fit, and shared core values. As emphasized by one of the respondents in the purchasing team: *“It’s quite fluffy actually, but it is about sitting down for dinner with the supplier and their management and ask yourselves: Do we get good vibes from them?”*. Effective communication and a strong collaboration culture are vital for ensuring smooth project execution, yet these aspects were often neglected in favor of the technical and commercial metrics in early supplier selections.

Additionally, when the supplier has been selected, the onboarding process for new suppliers is time-consuming and can introduce a number of inefficiencies. The need to introduce these new partners to their company and its company values is difficult and takes time but is necessary for building long-term supplier relationships. Early-stage supplier assessments had historically lacked consistency, often relying on the experience and intuition of individual buyers. This subjectivity led to variations in how supplier selection was made, sometimes prioritizing cost or technical specifications at the expense of long-term collaboration potential.

Over time, Northvolt has refined their supplier evaluation process to address these challenges. A key improvement has been to introduce a standardized evaluation framework with predefined criteria. By implementing this criteria framework, more fact-based decisions can be made. The criteria consist of six categories, each containing multiple sub-criteria. Using the AHP-methodology, scores are assigned to each criterion, with different weights applied based on importance. This enables structured comparisons across multiple suppliers, making the process more objective and data driven.

Long-term supplier collaboration has proven to be an efficient strategy for mitigating onboarding inefficiencies. By establishing strong and ongoing relationships with suppliers, the learning curve associated with new suppliers is eliminated, which saves both time and resources. This relationship also helps streamline operations by having on-going discussions around deliverables and expectations. A long-term relationship allows both the supplier and the battery producer to accumulate combined knowledge benefitting both. These strategic relationships are essential in creating partnerships that yield high profits. Both challenges and mitigation strategies mentioned can be seen in Table 9 below.

Challenge	Mitigation	Impact
Variation in supplier interpretations of specifications.	Standardized evaluation framework up to 50 criteria.	Improved objectivity and comparability in supplier selection.
Cultural differences in specification flexibility.	Enhanced communication by early alignment of requirements set in the evaluation criteria.	Reduces misunderstandings and prevent costly adjustments later.
Overemphasis on technical and commercial factors.	Include communication capabilities and cultural fit in supplier evaluation.	Stronger long-term partnerships and improved project execution.

Lengthy supplier onboarding.	With more rigorous evaluations, more long-term and strategic partnerships can be struck up, reducing onboarding inefficiencies.	Saves time and resources. This makes new negotiations with the same supplier smoother and more efficient.
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Table 9: Summary of challenges, mitigation strategies, and their impact for supplier evaluation and selection

4.2.4 Integration of maintenance perspective

Operating in a novel industry in the European context and purchasing production equipment with state-of-the-art technology comes with major challenges. One of these is the lack of internal know-how and what is important to consider when acquiring capital equipment. The production equipment in this context, is associated with high investment costs, often making it the key consideration when choosing among alternatives on the market.

This is one of the challenges identified at Northvolt, where initial focus was heavily on upfront investment costs, often overlooking future operational expenses, particularly those related to maintenance. As noted by one respondent from purchasing: *“Historically, maintenance was not really involved in early procurement decisions, and that caused issues later on when the machines were delivered. There was no documentation, or no one knew how to maintain it properly”*. This lack of early maintenance involvement made the machines difficult and expensive to maintain. Since battery production equipment is both complex and expensive, it is essential to have a cross-functional perspective, integrating expertise from different departments in the sourcing process. This is something that are being improved. For example, expensive purchases now require approval from a sourcing council consisting of key people from different departments ensuring their different perspectives are considered to make more holistic and informed decisions.

One tangible consequence of previously lacking the maintenance perspective in the sourcing process is related to agreements for spare-parts. Early purchases often lacked a structured part standardization, resulting in having numerous suppliers for similar components. In turn, this made it complicated to standardize maintenance approaches, leading to servicing complexities and inefficiencies, consequently causing higher operational costs. Further issues raised within this subject were how suppliers of production equipment sometimes integrated region-specific components. The origin of these components was sometimes not specified, making it challenging to obtain spare-parts whenever needed, creating additional issues to maintain the assets effectively.

A way to mitigate these challenges in purchasing have been to employ a more structured standardization policy of components to ensure greater availability of parts. Therefore, a standardized parts list has been established, where the case company in many instances demand their suppliers to use approved sub-suppliers for certain components. A visual summary of the challenges and mitigation strategies for this part is provided in Table 10 below.

Challenge	Mitigation	Impact
Overemphasis on initial investment costs, overlooking important operational aspects.	Embrace cross functional sourcing by involving expertise from other departments, both early in the process and before approval through a sourcing council.	Widening the evaluation process considering operational costs in addition to the upfront investment.
Fragmented supplier base for functionally similar components.	Implementing a standardized part list for components demanding suppliers to use approved sub-suppliers.	Improved spare-parts availability, simplified maintenance processes and cost savings.

Table 10: Summary of challenges, mitigation strategies, and their impact for integrating maintenance in the procurement process.

4.2.5 Short-term cost focus

This part is closely related to many challenges brought up in other sections. At an early stage in the journey for Northvolt, many crucial aspects were not appropriately considered. For example, most of the early sourcing was dependent on Asian suppliers partly due to their expertise, but mainly due to their cost-advantage compared to more regional suppliers. However, a lesson learned was how minimizing capital expenditures not necessarily led to the lowest total cost over the lifetime of the purchased equipment. Instead, the lack of long-term planning caused higher operational expenses where for example maintenance costs became an unexpected burden. Therefore, while the aim was to minimize initial investment costs, the total costs over the lifetime of purchased assets turned out to be of significant magnitude caused by overlooking factors driving operational expenditures.

Many of the aspects overlooked in earlier procurement processes have been explicitly elaborated in previous sections. For example, the cultural disparities between European producers and Asian suppliers, causing lengthy and complex processes with compatibility issues, the integration of maintenance considerations through standardized part lists, and incorporating clauses in contracts allowing change-orders without incurring immensely high change order costs must all be considered to avoid high future operational expenses. These issues have created serious financial consequences and has therefore led to changes in the approach of sourcing battery production equipment. The mindsets have changed, where machines with higher initial investment costs are now sometimes considered more profitable in the long run if it reduces operational expenses. Therefore, the sourcing department nowadays estimate the operational costs at an early stage to get a clearer overall picture of the investment, and finally suppliers are evaluated based on TCO leading to better financial planning and long-term profitability. For a concise overview of these challenges along with mitigative actions, see Table 11.

Challenge	Mitigation	Impact
Short-term cost focus leading to higher long-term operational expenses.	Implement a TCO approach in supplier evaluation to	More long-term financial planning, reducing unexpected costs and

	balance initial- and operational-expenses.	improved long-term profitability.
Dependency on low-cost suppliers without considering long term risk.	Diversifying sourcing to include suppliers not only offering low upfront costs.	Decreasing supply chain risks and better resilience through more balanced supplier selection.

Table 11: Summary of challenges, mitigation strategies, and their impact for Total Cost of Ownership (TCO)

4.2.6 Managing changes and flexibility in procurement

In the procurement of battery production equipment, changing equipment requirements is common. This is due to both the fast-paced environment with incremental and radical innovations in the battery production industry, and changing customer requirements that necessitate modification to previously set specifications. With this, new challenges related to cost, timelines, and supplier adaptability emerge. Initially, procurement contracts did not account for this need for flexible contracts, leading to costly change orders and delays when modifications to the battery production equipment were necessary.

One of the issues was that early procurement processes did not anticipate the extent of design changes required throughout a project’s lengthy lifecycle. The initial specification was often too broad, as the company was still in a phase of understanding what is needed for battery production. Therefore, suppliers were often required to adjust specifications mid-process, impacting cost and timeline. As one respondent from the purchasing department noted: *“At this time, we knew that our specifications couldn’t be very precise... but eventually it had to be changed, leading to additional costs”*.

In addition, these early contracts lacked provisions for handling such changes, meaning that any modifications incurred additional expenses that had not been planned for. Another issue was that design iterations were often introduced late in the procurement process, sometimes after suppliers had already started manufacturing. This not only increased costs, but also strained supplier relationships, as vendors had to accommodate changes that were not initially agreed upon. In some cases, these modifications required extensive renegotiations, further delaying project completion.

Over time, Northvolt developed its procurement strategy to better manage these challenges. One major improvement was the inclusion of flexibility clauses in procurement contracts, ensuring that modifications could be made without excessive cost penalties or lengthy renegotiations. This shift allowed for better cost control and reduced financial risks associated with changing equipment requirements. Also, another key improvement was investing more time upfront in defining specifications to minimize the need for later modifications. This involved closer collaboration between functional departments to make the specifications as robust and forward-looking as possible. See Table 12 for a visual summary of the challenge, employed mitigation strategy, and its impact.

Challenge	Mitigation Strategy	Impact
Changing equipment requirements over time	Flexibility clauses, or change orders, in procurement contracts that allow for changes of specific parts	Reduces costly renegotiation and delays. Removes bargaining power from supplier

Table 12: List of key challenge, mitigation strategy, and impact for managing flexibility in specifications.

4.3 Key Maintenance Challenges and Requirements

As the procurement of battery production equipment involves various stakeholders, aligning their perspectives and requirements is essential for ensuring long-term operational reliability. This chapter presents key maintenance-related challenges and requirements that emerged from empirical data, with a particular focus on the interface between procurement and maintenance functions. The findings reveal several structural and communication-related issues that hinder effective collaboration, leading to inefficiencies in specifying, acquiring, and maintaining production equipment. Four main areas of challenges and consequences were identified and will be discussed in depth in the sections below. For an overview of the identified challenges in this part, see Figure 8.

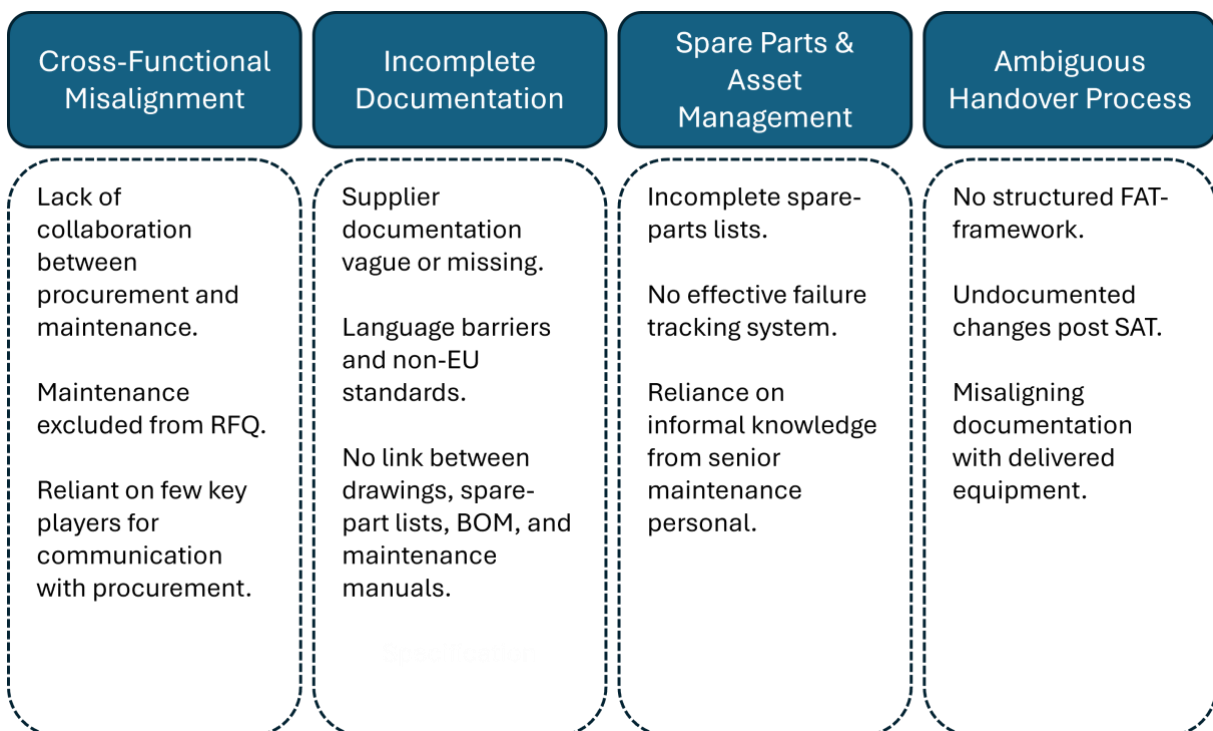


Figure 8: List of identified challenges from a maintenance POV

4.3.1 Misalignment between procurement and maintenance

The interaction between functions in a firm is essential for ensuring efficient and reliable knowledge transfers between them. If misalignments occur, this can lead to operational

inefficiencies, increased costs, and irritation within the company. At the case company, most of this cross-functional collaboration between procurement and maintenance has been performed by a few key players at the maintenance department. As one of these key players in the maintenance department described: *“One day I decide to leave and someone else comes in and he will find it really difficult to cope up with it because he has no idea what is going on”*. This issue was further stressed by several others in the maintenance department expressing that they had no interaction with the procurement function. However, when there is collaboration, it is these key players that handle it. If these people were to leave the company, the collaboration between functions would cease to exist. Rather than addressing inefficiency with the procurement process of battery production equipment, the communication between procurement and maintenance has primarily been about resolving current issues.

The lacking communication between procurement and maintenance is particularly evident in the purchasing process of new battery production equipment. Maintenance engineers or personnel are often not involved in setting specifications for specific equipment, resulting in the procurement team not fully considering long-term maintenance needs. Instead, the key players from the maintenance team are consulted after purchasing decisions have been made, limiting their influence on aspects such as spare part availability, ease of maintenance, and overall equipment reliability.

Additionally, maintenance requirements are often missing from RFQs. This means that suppliers are not explicitly designing their battery production equipment to be maintenance-friendly, resulting in equipment that is more difficult and costly to maintain over time. However, from the interviews it also became apparent that maintenance personnel need to reach a consensus on what criteria they should include in the RFQ. As one respondent from the maintenance team noted: *“While we really would need to integrate our perspective in the RFQ-process, we are not completely aligned in knowing what our desire is yet”*. It is not clear if the reason why some requirements are missing is due to lack of consensus within the company, or due to a lack of knowledge of these criteria because of the novelty of the industry.

The consequences of this misalignment between functions are significant. The lack of early maintenance involvement leads to equipment purchases that are difficult and costly to maintain, often resulting in unexpected maintenance challenges. The absence of maintenance-related criteria in RFQs, allows suppliers to design and deliver equipment without considering the serviceability. Furthermore, the reliance on a few key individuals for the collaboration between procurement and maintenance makes the process vulnerable to disruptions if these people leave the company. This lack of standardized cross-functional teams limits the organization’s ability to build established processes of incorporating maintenance aspects into the procurement of battery production equipment. For a condensed list of challenges and consequences, see Table 13.

Challenge	Consequences
Lack of structured collaboration between procurement and maintenance functions.	Procurement decisions are made without fully considering long-term maintenance needs, leading to high costs.
Minimal interaction between procurement and maintenance personnel.	Only key players in the maintenance function interact with procurement personnel.
Missing maintenance criteria in RFQs	Suppliers are not designing their battery production equipment to be maintenance-friendly due to not being a criterion.
Lack of consensus among maintenance personnel on RFQ criteria.	It is not discussed in the maintenance function what criteria would be important to incorporate in the RFQ.

Table 13: List of key challenges and consequences related to internal misalignments

4.3.2 Incomplete Supplier Documentation

Another critical challenge consistently brought up by the interview respondents are related to the quality and completeness of technical documentations provided by the suppliers. Several of the respondents working as maintenance engineers reported how documentation for the purchased production equipment is often incomplete, and sometimes entirely missing crucial details needed to plan and conduct maintenance effectively. In turn, this creates internal uncertainties regarding the correct procedures for inspecting, servicing, and replacing components for the different production equipment at site.

Furthermore, the respondents also highlighted that the quality of documentation differed significantly depending on the geographical location of the supplier. The equipment purchased from some suppliers was frequently mentioned as especially challenging. Documentation such as drawings, spare-part lists, BOMs, and maintenance manuals, were described as vague and lacking proper machine specific information crucial for conducting necessary maintenance tasks. One respondent from the maintenance team emphasized this issue, stating that *“some suppliers did not provide documentation with solid maintenance plans... even basic things like lubrication points were missing”*. This clearly shows signs of the cultural disparities between actors on what should be included with the production equipment. This provides further evidence that this is an immature market in the European context.

As a result, the maintenance teams faced challenges in interpreting these generic instructions correctly, forcing them to spend significant time on going through the documents and adapting them to include the required information. This process of correcting the maintenance documents was a lengthy and time-consuming process conducted iteratively once problems and breakdowns occurred, making most maintenance activities reactive. Therefore, the vague documentation provided by certain suppliers hindered effective preventive maintenance forcing the team to conduct reactive fire-fighting activities, while continuously updating the documents with accurate information. Furthermore, the documentation issues were further problematic due to language barriers and differences in technical standards among different

geographical regions. Respondents from the maintenance department explained how some technical manuals, spare parts lists, and engineering drawings were partly written in Asian languages, creating further obstacles for personnel lacking the language proficiencies to understand the content properly.

In addition, some respondents highlighted how differences in technical standards created additional challenges. One interviewee noted that *“Some suppliers does not follow the same standards as we do. Certain cable colors need to be maintained and everything should comply with EU standards, but that is not the case,* referring to issues with electrical wirings not aligning with European norms. This contributed to confusion and uncertainty among maintenance personnel when interpreting drawings and performing work on the equipment. The language barriers along with the deviation from European technical standards did not only make maintenance tasks more complex, but also increasing the probability of misinterpreting critical information. Therefore, such challenges increasing confusion among maintenance personnel introduce significant risks concerning equipment reliability and operational safety.

A further obstacle mentioned during the interviews was the knowledge gaps and cultural differences regarding documentation with some Asian suppliers, who did not deliver complete BOMs as explicitly required in the technical specifications. In one example, it was explained how the BOM was contractually agreed upon, but the supplier delayed its delivery of the documentation for up to a year or more. *“We have had cases where Asian suppliers did not send complete BOMs, even though it was a part of the technical specification. We waited for over a year in some cases, and even then, the documentation was still missing key information”*, one respondent explained. This clearly highlights the challenge of acquiring reasonable documentation from certain suppliers. All of this left the maintenance team without critical information, necessary for planning maintenance work, ordering spare-parts and understanding the overall composition of the equipment. Therefore, the absence of this documentation severely limited the ability to employ preventive maintenance routines, thus increasing the risks of unpredicted issues during operation requiring reactive countermeasures.

Another significant challenge identified from the interviews was the lack of integration between different key documents. In most cases, all the documents were provided. However, several respondents pointed out that the drawings, spare-part lists, BOMs, and maintenance manuals lacked cross-references. This made it particularly challenging to trace components through the maintenance system, identify critical parts, and to plan proper preventive maintenance activities. As a direct consequence of this, the maintenance teams reported how they frequently invested significant time and resources into reverse-engineering tasks.

Without complete documentations, they had to physically inspect machines and disassemble components to manually identify spare part numbers and maintenance needs. One respondent from maintenance described the situation by stating: *“We have all the mechanical drawings. We have all electrical drawings, but none of these are connected to each other. What*

we are doing is we are going to the machine that has broken down, we are checking it and then we are manually identifying the numbers and then we are checking whether we have it or if we must purchase it". This highlights how the incomplete documentation, with missing BOMs and spare part lists, sometimes made it impossible to identify what spare-parts would be needed, forcing the team to come up with creative solutions to the problems.

Additionally, respondents from the maintenance teams described how design changes or upgrades made by suppliers during manufacturing were rarely documented in the provided documents and spare-part lists. Especially in projects where some suppliers introduced improvements solving certain production issues, but without communicating back to the buyer. Therefore, the delivered equipment did not always align with the provided documentation, creating a lack of traceability and significant uncertainty for the maintenance team. Particularly in understanding what components are included in the equipment, and what is needed once a breakdown occurs.

When accepted by the specific supplier, the maintenance teams reverse-engineered the production equipment to manufacture the required spare parts in-house. Similar situations occurred when certain spare parts were unavailable in local stock. Due to the long distance to Asian suppliers, producing spare parts onsite often became a faster alternative, taking only a few weeks compared to waiting up to four months for delivery from Asia. This reactive workaround was mainly caused by incomplete supplier documentation, making it nearly impossible to plan and perform preventive maintenance effectively.

In summary, the empirical finding show how incomplete supplier documentation creates clear challenges for maintenance operations. These issues restrict the ability to perform maintenance tasks efficiently, and often force maintenance teams into reactive firefighting and workarounds. Furthermore, the lack of accurate and integrated documentation also complicates the ability of planning preventive maintenance activities effectively. The key challenges and consequences identified for this part are summarized in Table 14 below.

Challenge	Consequences
Incomplete technical documentations provided from suppliers often lacking important equipment specific details, requiring significant adaptations by the maintenance team.	Creates uncertainty regarding correct inspection and servicing procedures, forcing the maintenance team to iteratively correct documentation and rely on reactive maintenance rather than preventive tasks.
Language barriers and deviations from European technical standards creates additional difficulties.	Increases the risk of misinterpreting crucial information potentially causing issues with equipment reliability and operational safety.
Poor integration between different technical documents (drawings, spare-part lists, BOMs, and maintenance manuals).	Making it difficult to identify critical parts and plan preventive maintenance effectively.

Suppliers making changes during set-up of battery production equipment without updating the documentation handed over to the buyer.	Causing the issues derived from incomplete documentation, making maintenance rely on reactive countermeasures.
Incomplete supplier documentation and long lead-times makes it hard to identify and obtain the right spare-part in time when failures occur.	Maintenance teams forced into creative workarounds to manufacture their own spare-parts to minimize the downtime during production stops.

Table 14: List of key challenges and consequences related to incomplete documentation

4.3.3 Spare Parts Management and Asset Management Issues

Spare parts management and classification is one further area being impacted by the documentation issues described in the previous section. The empirical findings from the interviews show how incomplete supplier documentation complicates the ability to manage spare part inventories, assess component criticality and plan procurement effectively.

Many of the respondents mentioned how the spare-part lists acquired from suppliers often were incomplete or failed to include the actual maintenance needs of the battery production equipment. This forced the maintenance teams to manually adjust the spare parts list during operation to reflect the reality. In many cases, critical components were missing or at least not accurately identified in the spare-part lists, making it challenging to know what parts to prioritize and keep in stock to avoid severe production disruptions. In several cases, components that later emerged as critical to production were not initially classified as such from the supplier documentation, leading to unexpected shortages and procurement delays once certain failures occurred. This is further emphasized by the following quote from one of the maintenance engineers: *“For one machine, we have up to 2000 assets, but we have a spare parts list which has like 30 items which the supplier say is critical. But we have also identified that half of them is not even critical, so it was not even a well thought out list”*. This did according to the maintenance teams lead to reactive purchasing or even the need to reverse engineering and production of spare-parts inhouse because of stockouts. Therefore, due to absence of reliable supplier documentation, the maintenance personnel had to rely on their own judgment and experience to determine the criticality and importance of each component. Knowing the criticality of each asset is not straightforward, as the same spare part can be critical in one machine but non-critical in another. Without a broad understanding and complete documentation that captures this aspect, the risk of missing truly critical spare parts increases, which could severely impact the uptime of production equipment.

A consequence of these gaps was that the maintenance teams had to conduct time-consuming classification work themselves. One of the most common approaches brought up was the use of ABC-analysis to categorize the spare parts and assets based on their importance and impact on production. One respondent from maintenance said, *“We had to do an ABC-analysis to*

understand which assets are important, and which ones are not, and then we had to decide whether we want to buy it, whether we want to keep it in spare, and what the amount of spare should be”, highlighting how this manual analysis was forced to be conducted internally due to lacking supplier support. While this method helped in structuring the inventory to some extent, the lack of supplier support and accurate documentation meant that these analyses were based on quite limited information. Consequently, this classification had to be updated iteratively as new failures emerged during operation. This in turn increased both the workload and uncertainty for the maintenance department already operating in a complex and challenging environment.

This empirical finding extends beyond spare part classification and issues with inventory management by creating noteworthy obstacles for employing systematic failure tracking. Several respondents emphasized how the absence of correctly structured asset classification complicated failure reporting, in turn making it difficult to prioritize maintenance efforts accurately. This is exemplified by one maintenance engineer saying the following: *“We have breakdowns, we solve them. Those breakdowns come again, we solve them again, but there is no active discussion happening... We cannot track recurring failures or do proper root cause analysis”*, referring to the lack of preconditions for a functioning reporting system. As a result, maintenance teams were often forced to rely on informal knowledge sharing and experience-based problem-solving rather than data-driven insights to identify those recurring issues. Consequently, this complicated the work of identifying root causes of problems and detect failure patterns that could facilitate the implementation of preventive maintenance strategies.

With this, it is evident how the inaccurate asset classification originating from the supplier documentation, complicated failure tracking and therefore preventing the transitioning towards a more preventive approach. Without clear historical data, maintenance teams struggled to tailor preventive maintenance schedules and calculate important reliability metrics, both of which are critical components for long-term planning and efficiency improvements. Instead, maintenance often remained reactive, constantly coping with unexpected breakdowns and production stoppages, further limiting the possibility to allocate resources to essential improvement projects.

To conclude, the findings show how the absence of accurate supplier documentation leads to unreliable spare parts classifications and a lack of structured failure tracking. This results in inventory management inefficiencies, increased risk of production stoppages, and prevents maintenance teams from shifting focus towards preventive work and long-term planning. Consequently, this forced the maintenance teams to spend significant time and resources on manual corrections and reactive problem-solving. The key challenges and consequences discussed relative to spare parts management and classification are summarized in Table 15 below.

Challenge	Consequences
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Incomplete spare part lists from suppliers.	Maintenance teams forced to manually adjust the documentation during operation, increasing workload and uncertainty
Inconsistent or missing classification of components in the provided spare-part lists.	Resulting in stock shortages, prolonged production stoppages and reactive countermeasures such as urgent purchases or reverse engineering/inhouse production. Creates additional work to correct classifications through internal ABC-analyses.
Missing preconditions for effective failure tracking system.	Limits the ability to document and track failures, leading to reliance on reactive maintenance instead of preventive strategies.
Forced to conduct reactive work to correct provided documentation.	Taking time and resources from more long-term planning and preventive maintenance work.

Table 15: List of key challenges and consequences related to spare-parts management and asset management

4.3.4 Ambiguous Handover Process

Another important area discussed during the interviews was the occurrence of supplier-driven modifications both post expediting at suppliers' site (FAT) and the delivery of equipment at the buyers' site (SAT). As discussed in the previous challenges, equipment often arrived with discrepancies between the documented components and what really was included. Some respondents highlighted how equipment in some situations arrived at the site with undocumented changes or missing components that were not present or identified during field expediting in the FAT-phase.

Furthermore, it was emphasized how structured and standardized frameworks guiding what to control during the FAT-process often was lacking, where instead much of the work was based on the experience by the individuals expediting. As one of the maintenance engineers stated: *"We still do not have an approved FAT structure or document for any machine. We do have a very generic one, but it does not hold any good. Slurry mixing has different requirements than a coating machine. We need separate FAT structures for each of them"*. This unstructured way of expediting the purchased battery production equipment can be considered a weakness, potentially allowing equipment arriving with deviations from the pre-defined specifications.

A further issue mentioned related to this was how suppliers, at times, continued making modifications to the equipment even after the SAT. Suppliers remained onsite, where respondents experienced that adjustments were made without proper communication or documentation by external engineers. As stated by one of the interviewees from maintenance: *"There are still lots of external engineers from the suppliers onsite, tweaking things as they wish. They consider it to still be in the SAT-phase, but in many cases, we feel that the handover has already happened"*. This is something that some of the respondents have identified as a potential cause to the deviations between the final delivered state of the equipment and the

documentation provided by the suppliers. These experiences hints that the process of transferring responsibility from suppliers to the buying company during the SAT is not clearly defined. With a more clearly defined handover process, these undocumented changes would not be allowed.

Respondents from the maintenance team further explained how such supplier-driven modifications, often went undocumented due to differing views on documentation practices. It was explained how design changes or upgrades were implemented by the suppliers to solve issues or improve the performance, but they were not shared with the buyer. This practice does according to the same respondents differ significantly from European standards, where even minor changes are formally documented and integrated into drawings, spare-part lists, BOMs, and maintenance manuals. These undocumented changes meant that the delivered equipment did not fully align with the available documentation, increasing the probability of errors or failures during maintenance.

Furthermore, such undocumented modifications can be considered as a potential factor contributing to the previously highlighted challenges. For example, the inconsistencies in spare parts documentation and asset classification might originate from the late-stage supplier modifications not reflected in the provided documentation. Consequently, the need to verify the equipment conditions with inaccurate details on hand is a factor diverting the focus by spending more time on reactive countermeasures rather than more proactive maintenance efforts. These reactive corrections added further unplanned costs while elevating an already high maintenance workload.

Respondents also reflected on how cultural and business practices differed, especially with suppliers lacking experience working with European companies and vice-versa. Even when clear contractual agreements required delivery of updated documentation, including BOMs, suppliers often failed to comply. Members from the maintenance team described how they spent months, and in some cases, even years on requesting this information. Consequently, this caused significant delays making it merely impossible to establish great control over the equipment's technical status. In contrast, more mature industries, such as automotive manufacturing, were described as having stricter documentation standards and more established routines. As one respondent in the maintenance team noted: *"According to my previous experience in working towards the automotive industry these problems did not exist. Of course, we had some conflicts with the suppliers, but the standard documentation was always supplied"*.

To summarize, the supplier-driven modifications taking place both after FAT and SAT may partly explain why the documentation provided by the suppliers deviates from the actual equipment delivered. This added to the challenges faced by the maintenance organization, increasing the uncertainty in spare parts management and complicating component classifications. Table 16 below summarizes the key challenges related to the ambiguous handover process and post-delivery modifications.

Challenge	Consequences
No clear evaluation framework for the FAT-process.	Relying too much on individual judgment and informal knowledge, increasing risks of missing aspects making the equipment deviate from agreed specifications.
Unclear transfer of responsibility after FAT/SAT	Modifications of the equipment post SAT, leading to discrepancies between what is delivered and the agreed specifications.
Failure to deliver updated documentation or BOMs as agreed upon.	Critical information for preventive maintenance and spare parts planning lacking, increasing reliance on reactive work and creating long-term knowledge gaps about the production equipment.
Modifications and undocumented changes occurring post-delivery.	Reactive maintenance becomes necessary when discovering undocumented parts, potentially reducing equipment reliability and increasing downtime.

Table 16: List of key challenges and consequences related to ambiguous handover practices.

5 Conceptualization

The purpose of this chapter is to propose and present a set of boundary objects that can address the challenges and misalignments between procurement and maintenance identified in the previous chapter. These boundary objects were classified as either internal (within the firm) or external (across firms). The conceptualization is based on the idea that boundary objects can help bridge knowledge gaps, supporting cross-functional behavior. This chapter begins by introducing the three internal boundary objects: human intermediary, a cross-functional RFQ-Framework and workshops. It is then followed by the two external boundary objects: Acceptance test framework and Expert regional supplier-specific teams (ERSST). For each boundary object, the specific challenges it is designed to address are clearly outlined and discussed. Some of these challenges may appear similar but differ in nature due to being viewed from distinct functional perspectives. The chapter will conclude with a table summarizing how each boundary object mitigates specific challenges.

5.1 Internal Boundary Objects

To address the internal challenges found between procurement and maintenance, three internal boundary objects are proposed in this section. These boundary objects will operate within the organization and aim to foster cross-functional collaboration by enabling knowledge sharing, aligning goals, and creating shared understanding. The selected internal boundary objects include a designated human intermediary role, a cross-functional RFQ-framework, and structured workshops. While the intermediary role contributes with continuous cross-functional integration, the RFQ framework ensures involvement of all crucial actors, and workshops support collaborative learning and adaptation over time. For a brief overview of how the boundary objects interact and complement each other, see Figure 9.

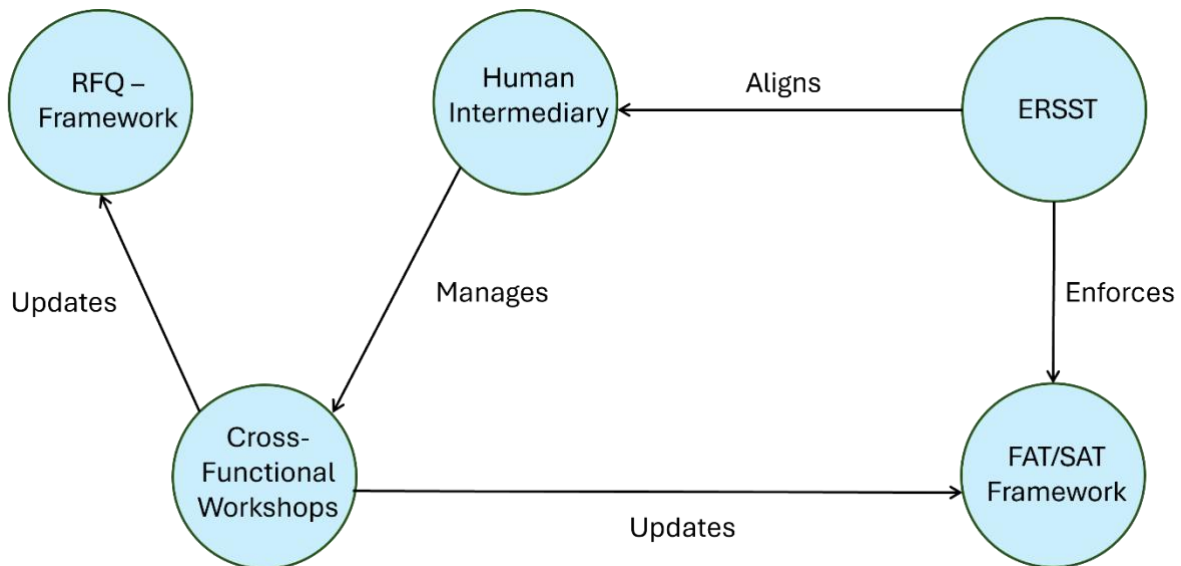


Figure 9: A brief overview of how the boundary objects interact and complement each other

5.1.1 Human Intermediary

The first internal boundary object is a human intermediary, which is a key function operating as a linking role to create alignment in the internal processes of the organization. By facilitating communication, coordination, and knowledge-sharing across the organizational interface of procurement and maintenance, this individual serves an essential function in improving cross-functional alignment in the sourcing process. Furthermore, this intermediary plays an important function in synchronizing all the internal boundary objects into a comprehensive system. By taking ownership of them, they ensure that the Cross-Functional RFQ-Framework are updated and that the workshops run smoothly supporting the sourcing process in general.

This type of role becomes particularly valuable in the context of acquiring battery production equipment due to the technical complexity of the equipment, and the long-term consequences caused by early-stage sourcing decisions. Therefore, the individual assigned for this key role must have a wide set of competencies by combining a technical understanding with dedicated know-how in procurement processes. Having a clear understanding of both parts is essential, since the intermediary must not only understand and translate technical requirements from maintenance staff, but also align these with the strategic goals and commercial constraints in the procurement process. However, this individual does not need to be an expert within both fields, but rather having a broad understanding of how the functions interrelate.

In this way, the human intermediary acts as a boundary object bridging both semantic and pragmatic knowledge barriers according to the definition by Carlile (2002). First, it has a crucial role in translating knowledge and needs across the boundary of purchasing- and maintenance-departments. Considering the differences in knowledge bases of personnel between these divisions, there is therefore a clear semantic knowledge boundary where concepts are interpreted differently. To exemplify this, both departments are aware of the necessity of having reliable production equipment that are easy to maintain, but how people interpret and

translate this into clear requirements might differ between the departments. For this reason, a boundary-spanning individual having expertise in both subjects, can operate at the interface between both functions ensuring that the meaning is preserved when knowledge is transferred across organizational departments.

Another aspect to bear in mind is that different departments often have competing interests and priorities, thus creating a pragmatic knowledge barrier. In this context, the intermediary function enables alignment of goals across functions. For example, decisions that previously were made in purchasing focused strongly on minimizing capital expenditures, often leading to higher operational costs due to maintenance inefficiencies. With this role in place, discussions between different stakeholders can be initiated earlier in the process, allowing tradeoffs such as cost and serviceability to be addressed more transparently. In this way the intermediary also acts at the pragmatic knowledge boundary, not only translating knowledge but also helping by transforming competing interests into shared objectives.

Several empirical challenges identified in the interviews and presented in the results section further support the relevance of this role. These include the lack of collaboration between key internal stakeholders, the absence of structured collaboration between procurement and maintenance, and minimal interaction between these functions in day-to-day operations. The intermediary function addresses these challenges by taking the lead of internal coordination and driving early involvement across departments. These contributions are further shown below in Table 17, summarizing how this boundary object supports resolving key internal alignment issues.

Boundary object	Challenge	Function
Human Intermediary	Lack of collaboration between key internal stakeholders.	Lead the specification-setting process and ensure involvement from all relevant departments.
	Lack of structured collaboration between procurement and maintenance.	Establish and maintain structured collaboration through recurring cross functional activities such as workshops.
	Minimal interaction between procurement and maintenance.	Act as a bridge between functions to encourage continuous interaction and feedback.

Table 17: List of challenges and role of Human Intermediary

5.1.2 Cross-Functional RFQ-Framework

Building on the boundary spanning role of the human intermediary an additional boundary object supporting a more structured cross-functional collaboration is the cross-functional RFQ-framework. While the human intermediary acts at the organizational level, the framework works as a standardized tool that helps improving the procurement process and the collaboration across departments. With a standardized tool working as a boundary object at the process-level it ensures that key functional requirements, especially those related to

maintenance and long-term operability, are clearly captured when initiating new sourcing processes.

The cross-functional RFQ framework acts as both a syntactic and semantic boundary object according to the definition by Carlile (2002). At the syntactic level, the framework provides a shared structure for specifying requirements to new sourcing processes, allowing the different departments to contribute with their expertise in a coordinated way. Furthermore, at the semantic level, it helps translating department-specific knowledge such as the maintenance specific needs, into terms that are both understandable and actionable by the procurement team. By having this in place, it ensures that all relevant functions get proper involvement before the RFQ is finalized and shared with suppliers, thus enabling more holistic decision-making in the sourcing process, and minimizing unexpected issues related to maintainability of the equipment. Additionally, this cross-functional RFQ-framework can also contribute at the pragmatic boundary. By better capturing the perspectives of each department and making them visible in this framework, the potential tradeoffs between different departmental goals also become more transparent. This creates greater conditions for balanced discussions while supporting more informed sourcing decisions accounting for both short-term and long-term needs.

Here, the empirical challenges identified in the results section are used to clarify key aspects to include in this framework. While these aspects based on empirical evidence provide a solid foundation, it is important to emphasize that this framework must remain dynamic and continuously updated as new lessons emerge. A summary of these challenges and how they can be addressed through the Cross-Functional RFQ-Framework is presented in Table 18 below.

Boundary object	Challenge	Function
RFQ-framework	Lack of collaboration between key internal stakeholders while setting specifications.	Ensure structured input from all relevant departments before finalizing RFQs.
	Regulatory, technical, and cultural disparities between buyer and supplier.	Set clear expectations on how information should be communicated and delivered by suppliers.
	Long-term maintenance issues due to supplier specific components.	Specify use of standardized, globally available components to ensure long-term serviceability.
	Variation in supplier interpretation of specifications.	Use structured formats and unambiguous language to reduce room for misinterpretation.
	Cultural differences in specification flexibility.	Align internal specification formats with supplier expectations, while maintaining clarity and control.

	Fragmented supplier base for functionally similar components.	Consolidate component requirements and define preferred sub-suppliers for consistency and maintainability.
	Changing equipment requirements over time.	Include flexibility clauses and define acceptable change-order conditions in the RFQ.
	Incomplete supplier documentation.	Make complete and specific documentation a formal part of the supplier's evaluation and contract requirements.
	Poor integration between different technical documents (Drawings, spare-part lists, BOMs, and maintenance manuals).	Require that all technical documents are properly linked and cross-referenced.
	Unclear transfer of responsibility after FAT/SAT.	Define clear transition protocols and responsibilities in both the RFQ and final supplier contracts.

Table 18: List of challenges and the implications for the RFQ framework

5.1.3 Cross-functional workshops

While the RFQ-framework provides a structured format for integrating cross-functional input in the sourcing process, it also requires a supporting forum where such input can be generated, discussed, and developed. To fulfil this role, workshops making these discussions possible are proposed as the third internal boundary object, encouraging cross-functional collaboration between procurement, maintenance, and other relevant stakeholders. This can help increase the degree of participation in the sourcing process, something emphasized as an important aspect when organizing purchasing departments (Bals et al., 2018). Led by the human intermediary, these workshops will create a common space for members of the different functions to discuss problems that arise from all perspectives. In this forum, representatives from each department will participate ensuring that their specific perspectives are captured. These representatives might be of a more senior level, but it is up to each department to properly select who represents their interests.

The purpose of these workshops is threefold. First, they ensure that maintenance-related needs and long-term operational considerations are addressed early in the specification and evaluation phases. Second, they provide a platform for knowledge sharing and clarification across departmental boundaries, reducing misunderstandings and siloed decision-making. By creating regular meetings between the functions, a more holistic understanding is likely to emerge across both sides. Third, the workshops will be closely linked to the cross-functional RFQ-framework, serving as a tool for gathering input and keeping the framework dynamic as new challenges and lessons emerge.

The workshops should take place at regular intervals, at a minimum quarterly. However, in certain phases of the procurement process, such as sourcing new suppliers, workshops can be held more frequently. To make the meetings relevant and well-prepared, participants are given the opportunity to submit discussion topics or concerns anonymously in advance. This not only allows participants to raise sensitive issues more freely but also ensures that the sessions reflect actual challenges experienced in day-to-day operations. Over time, as recurring challenges are addressed, the workshops may evolve from being highly structured sessions focused on known problem areas to more open discussions. In this way, the workshops can transition to a tool for continuous improvement and cross-functional learning. This flexibility allows the workshops to remain relevant even as the organization matures in its procurement practices.

As a boundary object, the workshop creates a shared space where knowledge from different departments can be translated, aligned, and negotiated. In line with Carlile’s (2002) typology, this workshop functions across all three knowledge boundaries: it supports syntactic exchange through shared terminology and the structured agendas; it enables semantic translation by helping participants interpret each other’s perspectives; and it facilitates pragmatic negotiation by engaging participants and solving competing interests. Therefore, it bridges boundaries by helping participants develop a common understanding of terms, requirements, and expectations. The relevance of this boundary object is further supported by several challenges highlighted by participants during the interviews, as presented in the results section.

The workshop address several of the underlying coordination and communication challenges identified in the results. Rather than solving singular problems, it acts as a forum where differences in points of view can be discussed. These discussions will help foster a cross-functional culture that takes diverse perspectives into consideration, rather than continuing with silo-focused decision-making. By establishing recurring workshops, the personnel from both departments will experience more formal and informal interaction, which over time helps build trust, mutual understanding, and a shared language. For an overview of the specific challenges that this boundary object helps mitigate, see Table 19.

Boundary object	Key Challenge	Function
Cross-functional workshop	Lack of collaboration between key internal stakeholders while setting specifications.	Provide a forum for discussing specification jointly across departments.
	Variation in supplier interpretations of specifications.	Create shared understanding and clarify ambiguous requirements.
	Cultural differences in specification flexibility.	Encourage awareness of supplier perspectives while aligning internal standards.

	Overemphasis on technical and commercial factors.	Facilitate discussion on soft factors to support long-term collaboration.
	Overemphasis on initial investment costs.	Encourage cross-functional input on long-term operational impacts.
	Short-term cost focus leading to higher long-term expenses.	Promote strategic thinking on total cost of ownership.
	Dependency on low-cost suppliers without considering long-term risk.	Support risk-based sourcing discussions and long-term planning.
	Minimal interaction between procurement and maintenance personnel.	Provide a recurring space for structured interaction between departments.
	Missing maintenance criteria in RFQs.	Enable early identification and inclusion of maintenance criteria should be included.
	Lack of consensus among maintenance personnel on RFQ-criteria.	Collect and align views on what maintenance criteria should be included.
	No clear evaluation framework for the FAT process.	Support development of FAT templates suited for different equipment types.

Table 19: List of challenges and the workshop functions

5.2 External Boundary Objects

From the interviews it became evident that there were not only knowledge boundaries internally, but also knowledge boundaries between Northvolt and its external stakeholders, particularly suppliers. To mitigate this issue, two external boundaries are proposed. First, a standardized Acceptance test framework is suggested to ensure structured and consistent supplier evaluation and handover procedures. Second, the establishment of expert regional supplier-specific teams (ERSSTs), consisting of senior representatives from key internal functions such as maintenance, procurement and law should be created.

These teams will assist in building the four pillars of supply integration (Paulraj et al., 2006). They support relational integration by creating long-term partnerships with suppliers, process integration by extending processes outside the firm, and information integration by establishing effective information flows enabling joint-problem solving. Altogether, they function as cross-organizational teams that help align internal and external actors. In summary, these two external boundary objects play a crucial role in bridging organizational knowledge boundaries with suppliers and reducing misunderstandings in the procurement processes moving forward

5.2.1 Acceptance test framework

The first external boundary object being proposed is an acceptance test framework for the FAT and SAT processes. Both processes are critical stages, ensuring that the delivered machinery meets the agreed-upon specifications both before shipment (FAT) and after installation at the customer site (SAT). However, based on the empirical findings several challenges arose because of the lack of structure, unclear responsibilities, and undocumented changes occurring during these stages. Consequently, to mitigate these risks, a standardized acceptance test framework is proposed as an external boundary object to facilitate alignment and transparency between the supplier and the buyer organization.

This acceptance test framework takes the role of a syntactic and semantic boundary object. First, at the syntactic level it provides a shared structure and language for documenting test procedures and acceptance criteria. Second, at the semantic level, this framework translates expectations between the buyer and the suppliers by clearly specifying what needs to be tested, what documentation must be provided during the tests, what constitutes a successful handover, and at what point the responsibility is being transferred to the buying part. In the empirical findings, it was evident how some suppliers more frequently delivered incomplete or inconsistent documentation, following technical standards deviating from those expected by the buying organization. Having a framework acting as a boundary object between the buyer and the external supplier, is therefore especially relevant when working with international suppliers who may follow different technical standards or have different documentation practices.

The current FAT-framework was described to often lack equipment specific-structures and more relying on generic checklists or individual experience. The lack of standardization in this context poses risks in missing essential verification steps during the testing phase, which might lead to unwanted consequences further on. Therefore, there is a need to develop specific FAT-templates for different equipment types, to support the evaluation team in making sure everything is verified. Similar challenges were identified in the SAT phase, where suppliers occasionally remained onsite after equipment was delivered continuing making adjustments without formal communication nor documentation. This created uncertainty around when responsibility had transferred to the buying organization, where in some cases the supplier considered the equipment to still be in the commissioning stages, while the buyer viewed the equipment as fully delivered. In addition, these undocumented changes during the SAT phase did often cause misalignment between the delivered equipment and the available technical documentation.

To address these issues, the acceptance test framework should therefore provide a standardized yet flexible configuration that can be adapted to different types of equipment. The framework shall define what is to be tested in these stages, what documentation is required, and how responsibility is formally transferred between the supplier and buyer. Furthermore, its development should be coordinated by the human intermediary ensuring

that relevant stakeholders are involved in its development. Furthermore, the recurring cross-functional workshops will serve as a platform in gathering input to the framework, evaluate its effectiveness, and incorporate lessons learned from future projects. A summarized overview of the key challenges identified through the interviews, along with the recommended parts to include in the framework, is presented in Table 20 below.

Boundary object	Challenge	Function
Acceptance test framework	No clear evaluation structure for FAT.	Define specific FAT templates for different equipment types with input from key departments.
	Suppliers making changes during set-up of battery production equipment without updating documentation	Establish formal end-of SAT document clarifying the transfer of responsibility.
	Equipment arriving with undocumented and/or unverified changes.	Require all changes during FAT/SAT to be documented and integrated into final documentation.
	Suppliers remaining onsite making undocumented changes.	Clarify roles and access-rights after the SAT to avoid unauthorized modifications.
	Misalignment between delivered equipment and available documentation.	Require that all technical documentation is delivered and verified before marking the FAT/SAT processes as complete.
	Inconsistent handover practices.	Introduce a formal handover checklist including the requirements from FAT/SAT templates, to be signed by both parties at each phase.

Table 20: List of challenges and the acceptance test framework recommendations

5.2.2 Expert Regional Supplier-Specific Teams

While the Human Intermediary serves as an internal boundary object bridging procurement and maintenance within the organization, the Expert Regional Supplier-Specific Teams (ERSSTs) are introduced as an external boundary object. Both aim to manage semantic and pragmatic knowledge boundaries, but they differ significantly in scale, scope, and context. Whereas the Human Intermediary operates individually to create internal alignment, ERSSTs function as cross-functional teams positioned at the interface between the organization and its suppliers. This difference in structure reflects the greater complexity and risk associated with external supplier relationships, particularly in the context of battery production equipment, where cultural, regulatory, and technical disparities have been identified as common. Therefore, a team-based approach is required to bring together multiple areas of expertise and ensure smooth collaboration with suppliers across different regions.

To address the boundaries between the case company and its external suppliers, the establishment of Expert Regional Supplier-Specific Teams (ERSSTs) is proposed as the second external boundary object. These teams are designed to enforce compliance, ensure alignment, and bridge communication gaps throughout the procurement and implementation of battery production equipment. ERSSTs consists of senior management and key personnel from diverse functions such as procurement, maintenance, finance, and legal, and will be responsible for specific regions or customers. Members of ERSSTs will split their time between their original job responsibilities and the ERSST. They primarily belong to their internal function but works as an extended contact point with the suppliers and the rest of the ERSSTs. Therefore, they are occasionally visiting suppliers making sure everything is aligned according to the agreements.

The ERSSTs serve several important purposes. First, they ensure correct and complete documentation is obtained and validated through the procurement process. Second, they act as the main point of contact for the suppliers, which brings advantages for both parties. For the supplier, it provides a consistent and familiar point of contact which allows for a long-term relationship to form. Similarly, it ensures better control over the sourcing relationship for the case company, as both sides know who to turn to for decision and potential questions. Third, they play a role in monitoring and verifying change orders, ensuring that any modifications during or after equipment delivery are formally agreed upon and documented. Additionally, the teams will be responsible for building relationships with suppliers and gaining insight into their extended value chains, including lower-tier suppliers. This deeper engagement enhances supplier evaluation processes and reduces downstream risks related to compliance, documentation gaps, and spare part availability.

ERSSTs are particularly important when working with international suppliers where cultural, regulatory, and technical standards may differ. In these contexts, traditional communication channels often fail to capture everything due to cultural and language barriers. According to Carlile (2002), such situations represent semantic and pragmatic knowledge boundaries, where differences in meaning and conflicting interests between actors must be translated and negotiated. By placing a cross-functional, regionally focused team closer to the supplier operating as a boundary object, the organization can more effectively manage the sourcing relationship and create a shared understanding of procedures. The relevance of ERSSTs is supported by several challenges identified in empirical findings. For an overview of the specific challenges this boundary object helps mitigate, see Table 21.

Boundary object	Challenge	Function
ERRST	High dependency on Asian suppliers due to cost-efficiency and high expertise.	Build strategic partnerships with evaluated suppliers to reduce risk while maintaining access to expertise and cost-efficiency.

	Regulatory, technical, and cultural disparities between buyer and supplier.	Act as the main communication channel to align supplier understanding with internal expectations and compliance standards.
	Maintenance issues due to supplier-specific components.	Ensure suppliers understand the need for standardized, globally available components to support long-term serviceability.
	Variation in supplier interpretations of specifications.	Clarify specifications early to ensure a shared understanding and reduce risk of misalignment.
	Cultural differences in specification flexibility.	Communicate clearly where flexibility is allowed and where strict compliance is required.
	Lengthy supplier onboarding.	Facilitate early engagement with selected suppliers to streamline onboarding and reduce delays.
	Changing equipment requirements over time.	Monitor evolving needs and communication changes proactively to maintain supplier alignment.
	Incomplete technical documentations from suppliers (Drawings, spare-part lists, BOMs, and maintenance manuals).	Follow up with suppliers to ensure documentation is complete, accurate, and tailored to equipment delivered.
	Language barriers and deviations from European technical standards.	Act as a local interface to overcome language and standards gaps and ensure compliance.
	Poor integration between different technical documents (Drawings, spare-part lists, BOMs, and maintenance manuals).	Coordinate with suppliers to ensure consistency and cross-referencing across all technical documentation.

	Suppliers making changes during set-up of battery production equipment without updating documentation.	Ensure all supplier modifications are communicated, approved, and reflected in final documentation.
	Inconsistent or missing classification of components in spare-part lists.	Review and align part classifications with suppliers to improve traceability and planning.
	Unclear transfer of responsibility after FAT/SAT.	Monitor handover procedures to ensure clear, documented transfer of responsibility.
	Failure to deliver updated documentation or BOMs as agreed upon.	Enforce documentation requirements and follow up on incomplete or missing deliveries.
	Modifications and undocumented changes occurring post-delivery.	Ensure that any post-delivery changes are documented and integrated into final records.

Table 21: List of key challenges and the ERSST function.

5.3 Summary of boundary objects, challenges, and functions

To conclude the analysis, this section provides an overview of all proposed boundary objects and the specific challenges they aim to address. The table below summarizes the insights from both internal and external boundary objects, outlining how each one contributes to bridging knowledge boundaries and supporting cross-functional coordination. By mapping the key challenges to each boundary object’s function, the summary serves as a practical reference for how the proposed solutions collectively support improved alignment between procurement, maintenance, and external suppliers, see Table 22.

Boundary Object	Key Challenge	Function
Human Intermediary	Lack of collaboration between key internal stakeholders while setting specifications.	Lead specification development and ensure all functions are involved
	Lack of structured collaboration between procurement and maintenance	Create structured collaboration mechanisms like workshops

	Minimal interaction between procurement and maintenance personnel	Bridge between departments and foster ongoing communication
Cross-Functional RFQ Framework	Lack of collaboration between key internal stakeholders while setting specifications.	Ensure structured input from all relevant departments
	Regulatory, technical, and cultural disparities between buyer and supplier	Clarify documentation expectations and communication standards
	Long-term maintenance issues due to supplier-specific components	Require use of standardized, globally available components
	Variation in supplier interpretations of specifications	Standardize language and format in RFQs
	Cultural differences in specification flexibility	Align internal and supplier expectations while maintaining clarity
	Fragmented supplier base for functionally similar components	Define preferred sub-suppliers and standardize components
	Changing equipment requirements over time	Include flexibility clauses in contracts and RFQs
	Incomplete supplier documentation	Make documentation requirements explicit in supplier evaluations
	Poor integration of technical documents	Require cross-referencing between BOMs and other documents
	Unclear responsibility transfer after FAT/SAT	Define handover protocols in RFQs and contracts
Cross Functional Workshop	Lack of collaboration between key internal stakeholders while setting specifications	Provide a forum for joint discussion of specifications
	Variation in supplier interpretation of specifications	Clarify and align expectations in specification development

	Cultural differences in specification flexibility	Raise awareness of cross-cultural differences in specs
	Overemphasis on technical and commercial factors	Discuss soft factors and improve long-term collaboration
	Overemphasis on initial investment costs	Encourage broader evaluation beyond CAPEX
	Short-term cost focus leading to higher long-term expenses.	Promote TCO perspective and long-term thinking
	Dependency on low-cost suppliers without considering long-term risk	Support risk-based discussions and supplier diversification
	Minimal interaction between procurement and maintenance personnel	Enable regular interaction and relationship building
	Missing maintenance criteria in RFQs	Encourage early identification of maintenance needs
	Lack of consensus among maintenance personnel on RFQ-criteria.	Facilitate alignment on maintenance criteria internally
	No clear FAT evaluation structure	Define FAT structure per equipment type with internal input
Acceptance Test Framework	Suppliers making changes during set-up of battery production equipment without updating documentation.	Formalize SAT completion and role handover
	Equipment arriving with undocumented and/or unverified changes.	Document and control of all equipment modifications
	Suppliers making changes during set-up of battery production equipment without updating documentation.	Clarify supplier responsibilities post-SAT
	Misalignment between delivered equipment and documentation	Link documentation delivery to FAT/SAT completion

	Unclear transfer of responsibility after FAT/SAT.	Use formal handover checklists to ensure alignment
ERSST	High dependency on Asian suppliers due to cost-efficiency and high expertise.	Build and manage strategic supplier relationships.
	Regulatory, technical, and cultural disparities between buyer and supplier.	Align supplier understanding with internal requirements.
	Maintenance issues due to supplier-specific components.	Ensure usage of standardized and widely available components.
	Variation in supplier interpretations of specifications.	Clarify and communicate specifications early.
	Cultural differences in specification flexibility.	Define clearly when flexibility is allowed and when there must be strict compliance.
	Lengthy supplier onboarding.	Support efficient supplier onboarding.
	Changing equipment requirements over time.	Proactively manage communication and evolving needs to keep suppliers aligned.
	Incomplete technical documentations from suppliers (Drawings, spare-part lists, BOMs, and maintenance manuals).	Ensure completeness and accuracy of supplier documentation.
	Language barriers and deviations from European technical standards.	Bridge language and technical standard gaps.
	Poor integration between different technical documents (Drawings, spare-part lists, BOMs, and maintenance manuals).	Coordinate with suppliers to ensure cross-references across all technical documentations.
	Suppliers making changes during set-up of battery production equipment without updating documentation.	Approve and track supplier modifications.
	Inconsistent or missing classification of components in spare-part lists.	Align spare part classification to create better traceability.
	Unclear transfer of responsibility after FAT/SAT.	Monitor clear and documented handovers.
	Failure to deliver updated documentation or BOMs as agreed upon.	Enforce documentation compliance.
	Modifications and undocumented changes occurring post-delivery.	Document and integrate post-delivery changes.

Table 22: A summary of boundary object functions related to key challenges

6 Discussion

This chapter provides a structured discussion of the empirical findings, beginning with an analysis of the key procurement challenges and the proposed boundary objects addressing them. Subsequent sections examine underlying organizational factors such as path dependency and rapid scaling, followed by managerial and theoretical implications derived from the study. The chapter concludes with a reflection on methodological considerations, ethical and sustainability aspects, and directions for future research.

6.1 Discussing the results

The empirical findings identified several recurring challenges within the procurement of battery production equipment, whereas many of them stems from the fast-paced growth of the case company and the complexity of sourcing in an industry characterized by rapid technological development. Among the most critical was the lack of early involvement of the maintenance function in sourcing processes, leading to equipment specifications not accounting for either long-term maintainability or proper spare part availability. This issue aligns well with previous research emphasizing the importance of procurement practices focusing on TCO (Ellram 1995), and the integration of maintenance considerations in early stages of sourcing processes.

Furthermore, the sourcing process at the case company was heavily influenced by high supplier dependency, particularly on Asian suppliers. This created a number of challenges related to CE-compliance, documentation quality, and the availability of spare parts. The differences in technical standards and expectations between regions caused misalignments, increasing the operational costs, and extending lead times for replacement parts. The provided documentation was often incomplete or delivered late, which significantly impacted the ability to perform preventive maintenance and implement structured asset management at the case company. Internally, the company faced challenges in fragmented communication across the procurement and maintenance function. Many of the processes were dependent on the implicit knowledge of certain individuals, resulting in inconsistent practices and limited organizational learning. Specifications were therefore developed with limited cross-functional input, leading to costly consequences for increasing operational expenses. Finally, the lack of standardized procedures during the FAT/SAT phases caused confusion regarding equipment acceptance, undocumented modifications, and unclear transfers of responsibility.

These challenges reflect both syntactic issues with lacking shared formats and documentation; semantic barriers with differences in interpretation across departments and geographies; and pragmatic boundaries with conflicting goals as defined by Carlile (2002). Addressing these boundaries is crucial, not only for reducing operational risks but also for improving the overall efficiency and maturity of the procurement process. To respond to these challenges, this study

explored the design and integration of boundary objects working as coordination mechanisms across internal and external knowledge boundaries. In line with Carlile's (2002) typology the proposed system of boundary objects was purposely structured to address all three boundary types, through a combination of human roles, standardized tools, and interactive processes.

The human intermediary emerged as a key internal boundary object being responsible for translating and aligning goals across functions. This role ensures that long-term operational requirements are accounted for early in the sourcing process, addressing the pragmatic boundaries between procurement and maintenance that may have conflicting priorities. By combining technical and procurement knowledge, the human intermediary plays a central role in guiding specification development, coordinating decisions between departments, and leading the workshops to promote continuous improvements and a learning organization. In addition, this role supports the semantic knowledge boundaries by helping different functions interpret requirements in ways that are mutually understood, especially when translating operational maintenance needs into actionable procurement terms.

Furthermore, the cross-functional RFQ-framework was designed as a practical boundary object with the aim to capture input from all relevant departments in a structured and comparable format. It primarily operates at the syntactic and semantic levels by creating a common structure for defining supplier requirements and translating department-specific needs into procurement terms. It also serves an important purpose in facilitating early involvement of stakeholders ensuring alignment before extensive supplier engagement. In addition, workshops were introduced as a dynamic, interactive boundary object promoting a room for discussions and negotiations to create mutual understanding cross functions. They contribute to all three knowledge boundaries by providing a forum where both misunderstandings can be brought up and goals can be aligned through recurring interactions and dialogues.

Externally, the acceptance test framework and the ERSST teams serve as boundary objects between the case company and its suppliers. The acceptance test framework provides a shared reference for verifying equipment performance and ensuring that documentation is complete before responsibility transfers. It addresses both syntactic boundaries through structured templates, and semantic boundaries by clarifying expectations in the cross-regional contexts. Furthermore, ERSSTs composed of cross functional personnel focused on specific supplier regions, act at the semantic and pragmatic boundaries to manage supplier communication, align expectations, and resolve compliance gaps. These teams therefore act as relational intermediaries, working with building up conditions for long-term partnerships while enforcing documentation and standard compliance.

Collectively, these boundary objects form a complementary system targeting different phases of the procurement process. Their value lies not only in formalizing knowledge transfer, but also in forming preconditions for continuous organizational learning and improving the maturity of sourcing practices. Importantly, this study illustrates that boundary objects are

most effective when implemented as a system rather than as isolated tools. Their complementarity, where static objects like frameworks are supported by human and interactive ones like the intermediary-role and workshops, contributes to greater knowledge integration. This systemic approach not only improves procurement maturity but also supports organizational learning by creating structured practices for transforming implicit knowledge into tacit knowledge as emphasized by Nonaka and Takeuchi (1995). However, it is also important to recognize that the relative importance of these boundary objects may shift depending on the organizational context and phase of growth.

Finally, as the organization scales and matures, the implementation of boundary objects might become increasingly challenging. The structured use of frameworks, role definitions, and collaboration routines can become difficult to maintain across growing teams, sites, and additional international interfaces. Therefore, static templates must be regularly reviewed and updated, human roles need clearly defined authority and support in expansion, and learning forums like workshops must evolve in line with the growth of the firm. This reinforces the need for boundary objects to be structured and adaptable in accommodating to growing operational complexity.

6.2 Path dependency, scaling & skilled people

While many of the challenges presented in this thesis are addressed through solutions such as boundary objects, it is also necessary to acknowledge the deeper factors that have shaped these challenges. One such factor is the path dependency of certain decisions created by rapid scaling of production. The empirical findings indicate that several of the observed inefficiencies are not due to lacking competence from the employees, but rather a reflection of the organization's course and external pressure to scale quickly. From the interviews, it also became evident that decisions in early procurement phases were often made under time pressure. This is especially evident in the scaling of production, where capital equipment at earlier stages was ordered before fully understanding the maintenance or operational implications. This type of rushed decision-making can be traced back to pressure from top management, aiming to maintain high momentum and market competitiveness.

While understandable in a high-growth environment, this approach limits the organization's ability to reflect, learn, and build internal processes. Several of the challenges identified in this thesis, such as incomplete documentation, limited maintenance integration, and reliance on reactive problem-solving, are not groundbreaking in themselves. In fact, many could have been anticipated and avoided if the company had been giving them time to gradually build up its capabilities. Instead, the organization was expected to deliver at scale before foundational routines were fully developed. This led to a situation where ad hoc solutions became the norm, and early decisions created a path dependency that is now difficult to reverse.

Moreover, the presence of capable individuals did not prevent these issues. As some respondent noted, the organization is full of skilled and motivated people. However, without

the necessary time, support structures, or coordination mechanisms in place, even highly competent individuals struggled to act proactively. Smart people were pulled into fire-fighting mode, reacting to immediate problems rather than being empowered to address root causes. In this sense, many of the challenges faced by the case company are less about technical knowledge and more about organizational maturity. If the company had been allowed to “grow into its shoes”, with more room for trial, error, and iteration, several of the costly missteps might have been avoided.

6.3 Managerial Implications

The findings from this study provide several insights and managerial implications for firms involved in strategic procurement of complex production equipment, such as in the battery production industry. Based on the empirical data gathered through interviews, one of the most critical insights is the need to enable cross-functional collaboration at early stages of the procurement processes. The lack of structured interaction between purchasing and maintenance functions was recurrently emphasized as a driver of operational inefficiencies, costly maintenance issues, and difficulties in supplier management. Therefore, managers are recommended to establish governance structures and boundary objects, such as clear documental frameworks, structured workshops, and even designated organizational roles (e.g., Human Intermediary ERSSTS) to ensure that technical, operational, and commercial perspectives are systematically integrated at an early stage in the sourcing process. These recommendations build upon and is supported by the organizational design research for purchasing and supply organizations (Bals et al., 2018) but are derived from the observed challenges in the industrial setting of battery producers.

Another managerial implication of this study relates to the topic of cost assessment in purchasing processes. The empirical findings revealed how the initial procurement decisions focused heavily minimizing initial capital expenditures, often leading to higher unanticipated operational costs, due to maintenance complexities and issues with spare parts management. Therefore, managers in this context should really shift towards implementing a TCO perspective and systematically evaluating both upfront costs and expected operational expenses during the lifetimes of assets. While this TCO concept is well established in theory (Ellram, 1995), this study highlights how its absence in practice within an emerging manufacturing sector like battery production can lead to substantial financial and operational risks, thus further emphasizing its importance.

In addition, the findings highlight the necessity of understanding and managing cultural differences in international supplier relationships. The empirical findings showed how the dependency on geographically concentrated suppliers in the Asian region, led to challenges concerning technical standards, regulatory compliance, and documentation practices. These challenges did not only reflect operational aspects, but also mirrored the deeper cultural and regulatory misalignments having tangible impacts on maintenance operations and long-term equipment reliability. To manage these risks, managers are recommended to complement the

previously discussed TCO-perspective by integrating considerations of cultural compatibility in the supplier evaluation processes. By this, firms can better anticipate and mitigate misalignments that might occur during procurement, equipment delivery and long-term operational support.

Moreover, the findings further emphasize the importance of creating preconditions for organizational learning capabilities. As this industry is characterized by high pace of technological development, it is not sufficient for firms to rely on static processes. Instead, companies within this sector must actively form mechanisms allowing continuous feedback, reflection, and adaptation across procurement and maintenance functions. Practices involving human links between departments, structured discussions forums, and iterative updates to sourcing frameworks would support this greatly. Creating such mechanisms is a managerial recommendation that would help their organization becoming a learning organization, where ongoing learning and capability development are integrated in the daily operations (Senge, 1990). This approach would allow firms, not only react to problems, but proactively evolve their procurement practices in response to internal learnings and external changes.

In addition to creating these learning practices, the empirical findings suggest how improvement efforts should not focus on isolated tools, but on building and continuously updating an integrated system of boundary-spanning mechanisms. Instead of treating roles, processes and relational structures in isolation, organizations should view them as interconnected elements reinforcing each other. For example, the five proposed boundary objects in this study are all related to each other and should be seen as a cohesive system designed to bridge knowledge boundaries at a systematic level. This systematic approach reflects the concept of systems thinking discussed by Senge (1990) and ensures that knowledge boundaries not only will be temporarily mitigated but managed dynamically across the organization over time.

6.4 Theoretical Implications

The empirical findings of this study showed that managing procurement challenges in complex industrial environments requires more than isolated improvements. Rather, the integration of multiple boundary-spanning mechanisms including roles, processes, relational structures, emerged as important aspects to effectively address existing knowledge boundaries. This observation suggests important additions to the existing boundary object theory, which has traditionally focused on static objects for transferring knowledge across different functions. In particular, theoretical implications can be derived from how boundary management practices have evolved in this context.

First, the findings build upon and extend Carlile's (2002) theory on boundary objects. In this foundational work, it was primarily static artifacts, such as specification documents, prototypes, and shared models being emphasized as tools for bridging knowledge boundaries. In contrast, the findings from this study show how boundary objects in complex environments

are not limited to these static artifacts, and instead can take the form of human roles, relational structures and evolving processes. In this context, human roles refer to the position as the intermediary role; relational structures include mechanisms like cross-functional workshops and the ERSSTs; while evolving processes consist of tools such as RFQ-frameworks, acceptance test frameworks, and documentation templates designed to structure collaboration across functions. These elements do not operate in isolation, but instead interact as part of an integrated system that adapts dynamically to organizational needs. This perspective aligns with later extensions (Levina & Vaast, 2005), emphasizing the importance of the systemic and dynamic nature of boundary management in high-complexity contexts.

Second, the research deepens the understanding in the context of Early-Supplier-Involvement (ESI) by emphasizing how the internal cross-functional alignment is a prerequisite for successful supplier collaboration. While ESI-literature (Wynstra et al., 2001) highlights the need to engage suppliers early to enhance project outcomes, the findings from this study show how some internal preconditions must be in place to support this. Without synchronized internal processes, especially between procurement and maintenance, early supplier involvement might not translate into real operational benefits. Therefore, this visualizes how internal organizational readiness is a critical success factor to effective ESI-practices.

Lastly, the study contributes to research in supply chain management by further emphasizing the importance of cultural factors in supplier relationships. The discrepancies in technical documentation practices, regulatory compliance, and communication styles between Northvolt and their suppliers were not solely soft obstacles but had tangible impacts on operational efficiency and costs. These findings support the growing view in supply management literature (Zhao et al., 2011; Ribbink & Grimm, 2014) that cultural compatibility is a critical dimension to consider during supplier selection and management.

6.5 Method discussion

This study adopted an abductive approach, supported by a sequential, qualitative case study design to explore the integration of maintenance considerations in the strategic procurement of production equipment. Abductive reasoning was particularly relevant due to the exploratory type of research, allowing theoretical insights to emerge iteratively from empirical findings. The three-phased design enabled a structured but flexible study, where earlier insights directly informed the last stage by the conceptual development of boundary objects. Here, Carlile's (2002) framework on knowledge boundaries was applied due to its strong alignment with the study's focus on addressing knowledge boundaries between procurement and maintenance functions.

The methodological choices provided rich and great insights in the industry reflected by the expertise and experience of the purchasing and maintenance professionals taking part. By relying on semi-structured interviews, the study captured nuanced and role-specific perspectives that might be overlooked in more quantitative approaches. The use of purposive

and snowball sampling, combined with investigator triangulation, enhanced the credibility and depth of the findings. Interview data was collected until thematic saturation was reached, defined as the point where no clear new themes or categories emerged. All interviews were conducted online, which increased the flexibility but limited opportunities for in-person interaction and non-verbal observations. To ensure trustworthiness, all interviews were transcribed, analyzed independently by both researchers, and cross-validated through collaborative coding sessions.

However, some limitations must be acknowledged. The most critical is that the proposed boundary objects have not been validated in practice, limiting the ability to assess their real organizational impacts. Therefore, this presents a natural direction for future research. In addition, the study also had to manage the challenge of Northvolt filing for bankruptcy during the process, which introduced difficulties in maintaining continuity and access to key stakeholders going through this uncertain time. While the data collection had largely been completed prior to this event, it may have influenced the participants' perspectives and added organizational uncertainty as something impacting the study.

Finally, the qualitative research approach prioritizing depth over breadth, makes the findings context specific. The focus on a single firm, although a highly relevant one in this rapidly developing industry, means that the generalizability might be limited. While the insights are based on Northvolt's organizational setting, they highlight underlying tensions and risks that are likely to arise in similar industrial settings. Recognizing these challenges, along with boundary objects to bridge them, can help other players in the industry avoid comparable issues. Therefore, the case-specific findings in this context can serve as important learnings for the industry as whole.

6.6 Ethical, societal, and ecological aspects

The findings of this study with the structured use of boundary objects can not only contribute to operational efficiency, but also broader societal and ecological goals within the battery manufacturing industry. The procurement of capital-intensive production equipment has a wide range of implications, and the implementation of coordination mechanisms such as boundary objects can support more responsible, transparent, and sustainable procurement practices.

From a societal perspective, boundary objects such as the human intermediary, the cross-functional RFQ framework, and regular workshops improve the knowledge integration across departments, leading to more informed and inclusive decision-making. This strengthens the organizational resilience and reduces dependency on individual actors, which is essential in this industry characterized by rapid growth and evolving demands. By supporting better supplier evaluation and ensuring that long-term operability and maintenance needs are integrated from an early stage, these objects contribute to the creation of more stable yet

scalable industrial processes, factors critical to the societal success of the green energy transition.

Moreover, the supplier-facing boundary objects such as the standardized FAT/SAT procedures and ERSSTs, enhance equipment reliability and reduce misalignments in global sourcing relationships. By promoting consistent documentation, standardized components, and clearly defined responsibilities, they support transparent and accountable procurement. These mechanisms also contribute to ethical sourcing by reducing uncertainty and increasing visibility into supplier practices and standards across the supply chain. With clearly defined expectations and structured verification procedures, buyers are better able to assess supplier compliance with relevant regulations, especially important when engaging international suppliers, where different norms and limited visibility can cause ethical or compliance issues. Additionally, by ensuring that maintenance personnel have access to accurate and updated equipment information, the boundary objects can also help enhance workplace safety.

Finally, from an ecological perspective, the introduction of the proposed boundary objects can contribute to more sustainable practices. With clear specification and improved documentation, the likelihood of receiving unserviceable or incompatible equipment is reduced and thereby lowering the risk of early obsolescence. Standardized spare parts and preventive maintenance strategies, both of which depend on accurate documentation, support resource efficiency and waste reduction. Since many of the ecological impacts in battery production are related to the energy and material use of manufacturing processes, prolonging the lifespan of equipment through better cross-functional coordination and improved maintainability can help mitigate long-term environmental effects.

Beyond their obvious function as organizational tools to address procurement and maintenance challenges, the boundary objects proposed in this study also have a broader relevance. They support ethical procurement by increasing transparency in supplier interactions and helping ensure compliance with labor, safety, and regulatory standards. Environmentally, they enable more sustainable equipment use by improving maintainability, reducing waste, and extending asset lifecycles. Moreover, by promoting collaboration and knowledge integration across internal functions and supplier relationships, these mechanisms contribute to more socially responsible and resilient industrial systems, extending their value into the societal areas as well.

6.7 Future research

While this thesis has proposed boundary objects as potential solutions to coordination and documentation challenges in the procurement of battery production equipment, future research is needed to explore how these solutions can be practically implemented in real-world settings. Specifically, there is a need for further investigation into how battery producers at different stages of maturity can adopt and adapt these boundary objects, and what organizational conditions are necessary for them to be effective.

One approach for validation would be to pilot the proposed boundary object in selected environments. For example, introducing a human intermediary role or trialing some type of prototype of the cross-functional RFQ-framework within a live sourcing process. Observing the outcomes and gathering feedback from involved stakeholders would offer insights into both feasibility and adoption barriers of those objects. Longitudinal case studies could also be valuable by further evaluating how roles like the human intermediary evolve over time, or how tools such as the cross-functional RFQ framework and Acceptance test framework perform when scaled across multiple procurement projects. This could provide deeper insights into the feasibility, limitations, and long-term impact of standardizing such practices within a rapidly growing industry.

Another interesting approach would be to engage with both actors in the battery industry and other manufacturing sections, including firms operating in more mature environment. This could involve interviews, focus groups, or joint workshops where practitioners are presented with the proposed boundary objects and asked to reflect on their applicability, limitations, and potential adaptations within their own organizational contexts. Such comparative input would help validate the transferability of the boundary objects beyond the case-setting and identify which elements are industry-specific versus more broadly relevant. Moreover, engaging with experienced practitioners could also bring up overlooked challenges or other complementary mechanisms, thereby refining the conceptual framework proposed in this study.

7 Conclusion

This study, conducted as part of the **MATTER@SCALE** research project, aimed to explore how maintenance considerations can be effectively integrated into the strategic procurement of production equipment within the battery industry, using the Swedish company Northvolt as a case study. The research was guided by three research questions. This section presents the findings related to each of these questions in the following sections.

The first part of the thesis required both mapping the procurement process and critical procurement challenges, along with their mitigation strategies specific to battery manufacturing. As detailed in section four, the results identified significant issues with setting specifications, supplier dependency and regional trade-offs, evaluation and supplier selection, integration of a maintenance perspective, short-term cost focus, and managing changes in the procurement process. These were analyzed across different steps of the procurement process; market research, setting specifications, supplier evaluation, and contracting. For each challenge, mitigation strategies that Northvolt had employed were also listed, including broader market screening, early cross-functional involvement, and total cost of ownership approaches.

The second part of the thesis examined key maintenance-related challenges of the procurement process within the battery production context. This investigation identified crucial issues including misalignment between procurement and maintenance departments, incomplete supplier documentation, ambiguous handover processes, and inadequate spare-parts management, and their consequences. These findings highlight the need for improved integration and coordination between procurement and maintenance to enhance operational efficiency.

The final objective of this research was to develop boundary objects specifically designed to address the identified challenges between procurement and maintenance. The creation of boundary objects such as the human intermediary, cross-functional RFQ frameworks, collaborative workshops, Acceptance test frameworks, and Expert Regional Supplier-Specific Teams (ERSSTs) provided practical tools to enhance cross-functional alignment, improve communication, and streamline processes. By integrating these boundary objects, organizations within the European battery production industry, like Northvolt can significantly reduce equipment downtime, extend the lifecycle of critical assets, and lower the total cost of ownership (TCO).

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Appendix A: Interview Guide - Purchasing

The following list presents the main questions used during the semi-structured interviews conducted for phase 1 of this study. Each question served as a starting point for a broader discussion, and all interviews included follow-up questions tailored to the respondent's background and answers. These follow-ups aimed to explore how practices have evolved over time and to identify specific challenges experienced in the procurement and specification process. When relevant, follow-up questions were also used to guide the conversation toward aspects related to maintenance, ensuring that this perspective was adequately covered in each interview.

Q1: What is your role at Northvolt?

Q2: What experiences (education and work) do you have before joining Northvolt?

Q3: For how long have you been employed at Northvolt?

Q4: How would you briefly explain the general procurement process?

Q5: What aspects are considered when setting specifications?

Q6: Who sets the specifications for new battery-production equipment?

Q7: What criteria are considered for selection of suppliers for production equipment?

Q8: How are these criteria used for evaluating suppliers against each other?

Appendix B: Interview Guide - Maintenance

The following questions were used when interviewing respondents with a maintenance perspective. A similar semi-structured approach was applied, where these main questions were complemented by follow-up questions to explore relevant experiences, changes over time, and perceived challenges.

Q1: What is your role at Northvolt?

Q2: What experiences (education and work) do you have before joining Northvolt?

Q3: For how long have you been employed at Northvolt?

Q4: How would you describe your role and responsibilities for maintaining production equipment?

Q5: How do you work with maintenance now compared to when you started?

Q6: What do you consider the main challenges for maintaining battery production equipment?

Q7: How would you describe your / the departments' involvement in setting specifications for new battery production equipment?

Q8: What are important aspects for newly purchased equipment from a maintenance POV?

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