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Human Capabilities for Smart Maintenance in Battery Production

A Case Study of Northvolt Ett

Master's thesis in Management and Economics of Innovation

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Abstract

This master's thesis investigates human capabilities required for Smart Maintenance in the Li-ion battery production industry, with a focus on Northvolt, a leading battery manufacturer in Sweden. The need for a well-structured maintenance organization becomes apparent as the battery production industry experiences rapid growth and increased complexity, driven by the demand for efficient and sustainable manufacturing processes. The study addresses three primary research questions: identifying the necessary capabilities for various maintenance roles, developing an effective training structure for new employees, and creating a repeatable framework for maintaining and updating competencies.

The research employs an abductive reasoning approach, combining case studies, thematic analysis, and semi-structured interviews with Northvolt's personnel. Key findings reveal the importance of capabilities such as data analytics, personal drive, digital tool understanding, prioritization skills, and teaching and training capabilities. Additionally, the study highlights the necessity of integrating theoretical knowledge with practical skills through multifaceted training programs, including learning factories and spaced repetition techniques.

The proposed training framework emphasizes the development of both general and industry-specific capabilities, ensuring that Northvolt's maintenance workforce can adapt to the evolving demands of Smart Maintenance. The thesis concludes with recommendations for continuous improvement and future research directions to enhance the sustainability and efficiency of battery production maintenance.

Keywords: Maintenance, capabilities, Smart Maintenance, Training, Battery Production, Industry 4.0

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We would like to start by saying this has been an exiting spring with a lot of learning of both Smart Maintenance and the battery industry. This report would not have been possible without several people we have worked closely with during the project and we would like to sincerely thank you for the time and effort. First, we would like to thank our supervisor at Chalmers University of Technology Jon Bokrantz. Jon has not only been a guiding light in the research providing relevant feedback and insights but also a calm voice when insecurity or stress been present, thank you!

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1

Introduction

The upcoming chapter introduces the master’s thesis, situating it within a broader context to outline the problem on which the thesis is based. This is further defined by a short problem description, its purpose and aim, and three research questions. Lastly, the report presents its limitations to narrow the scope, ensuring the project can be completed within the designated time frame from January to June 2024.

1.1 Background

The negative impact of human behavior on the environment has recently proven to be substantial. The need for change is considerable, leading to an increasing rate of electrification in society and industries. Most mobile devices need a battery to function in the electrified society, leading to a rapid increase in demand for Li-ion batteries (Fleischmann et al., 2023). Between 2022 and 2030 the market for Li-ion batteries is expected to grow with 27% annually, from 700 GWh annually to 4700 GWh globally. As of 2022, China was responsible for 79% of the world’s battery manufacturing capacity, while the manufacturers in Europe only account for roughly 10% (Statista, 2021). The European Commission has therefore established targets to increase Europe’s share of total global battery production while decreasing the environmental footprint of a battery over its life cycle (Council of the European Union, 2023).

To reach the goals presented by the European Commission companies native to Europe must begin producing batteries to compete with their Asian counterparts, meanwhile creating efficient processes to reduce the environmental footprint. The Swedish battery manufacturer, Northvolt, is therefore one of the key companies for this transition with its goal to produce the worlds greenest battery cells. To create a competitive production that fulfills these high ambitions, there is a need for efficient manufacturing, maximizing utilization of resources, and minimizing downtime. These factors demand a well-performing maintenance organization enabling high up-time for resource maximization. Maintenance approaches have evolved from “run-to-failure”, meaning fixing it when it breaks, to more complex strategies like predictive maintenance that analyzes historical data to determine maintenance activities. Consequently, the complexity of maintenance organizations has grown placing more stress on capabilities and effective use of resources (Mobley, 2002).

At the same time, the fourth industry revolution (Industry 4.0) with its digitaliza-

tion, automation, and data exchanges has started and is currently ongoing. The concept Smart Maintenance can be seen as a result of this revolution, encompassing predictive maintenance as well as more advanced technologies like IoT, AI, and machine learning in the maintenance organization to optimize production through high up-time (Bokrantz et al., 2020a). Despite these possibilities, Bokrantz et al. (2020c) describes how a common problem is large pools of data that it is never being used due to a lack of competence relating to analyses of data or usage of the analyzed result. The Smart Maintenance concept would ensure that the data would be used to a larger extent resulting in more objective decision-making to limit down-time. Smart Maintenance does not only utilize technological advancements to improve performance but recognizes the importance of context for the maintenance organization, including integration with both internal and external stakeholders to increase efficiency.

Given the current goals of electrifying society, reducing Europe’s dependence on China, and establishing a new industry in Sweden to lead this transition, research in battery production has become essential. Further, the increased recognition of maintenance in the last decades makes this area highly interesting, especially in the context of Industry 4.0. Therefore, this thesis looks into the maintenance organization within battery manufacturing and how human capabilities will change when processes become increasingly digitalization.

1.2 Context of study

The empirical context of this research will be at Northvolt in Sweden. As Northvolt is involved with the research project MATTER@SCALE and the project is highly relevant to this thesis, both Northvolt and MATTER@SCALE are presented in this section.

1.2.1 Northvolt

A key player in reaching the targets set by the European Commission is the Swedish company Northvolt. Founded in 2016 and currently Sweden’s largest battery manufacturer (Northvolt, 2024b). Northvolt creates cells for multiple purposes such as automotive, energy storage, and e-mobility charging. In line with the European Commission Northvolt aims to decouple the European battery demand from China and at the same time create the world’s greenest battery. This requires large production capabilities and Northvolt is currently operating Europe’s first homegrown gigafactory in Skellefteå, Northvolt Ett (Northvolt, 2023).

Since late 2021, the factory Northvolt Ett, just south of the arctic circle, has been producing battery cells and is currently ramping up production to reach its full capacity of producing 60 GWh annually, roughly equivalent to one million electric vehicles assuming a battery capacity of 60 kWh per car. At Northvolt Ett, individual battery cells are created from raw materials in three overarching steps upstream, downstream, and formation and aging. First, upstream handles all the raw materials

and mixes the active ingredients into two mixtures, one for the anode and one for the cathode. Second, downstream processes cut and fit the active materials into individual cell casings. Cell Assembly is part of the downstream processes and is the main focus area of the thesis and will be further presented in section 2.3. Third, formation and aging charges and stress tests the battery to ensure the right level of quality. All cells are later sent either directly to the customer or to Poland and the factory Northolt Dwa, Gdansk, for final assembly to customer-specific batteries.

Northvolt's ambitions require fast scaling both on a company level but also at Ett. Since the beginning of construction, in 2019, over 2000 employees have joined the company specifically at Ett (Northvolt, 2023). This puts high pressure on the organization to rapidly expand while production targets must be met. To achieve the required employee volumes while recruiting the right competencies, hiring is sourced globally (Northvolt, 2023). This adds further complexity to the organization, as it incorporates several different cultures within the company.

In 2030, Northvolt aims to deliver 150GWh of battery cells divided between three gigafactories in Europe and North America, secure a minimum of 50% recycled materials for all new cell production, and a carbon footprint for cell production of less than 10kg CO₂e per kWh (Northvolt, 2023). This clarifies the high ambitions of manufacturing green cells and makes Northvolt an interesting case for the study. To reach these goals, production at Ett needs to be optimized, with maintenance being a key process that can be improved by fully utilizing the data that is currently underused.

1.2.2 MATTER@SCALE

Due to battery manufacturing being a new industry, standards and best practices are yet to be formed. MATTER@SCALE is a research project founded by Vinnova and coordinated by Chalmers University of Technology (Vinnova, 2023). The purpose is to achieve long-term sustainability in the Swedish battery production industry, with a focus on the maintenance organization in Li-ion battery production. This thesis is a part of the MATTER@SCALE project and will investigate human roles and capabilities for maintenance in battery production, strategies for these capabilities' deployment, and mapping of desired competencies.

1.3 Problem description

A combination of rapid expansion with large volumes of recruitment together with an aim to reach Smart Maintenance puts a lot of pressure on training and employee development. Northvolt wants to develop a clearer view of what capabilities are necessary for different positions within the maintenance organization when becoming more data-driven. To efficiently transit to a Smart Maintenance organization, Northvolt must be aware of what competencies and capabilities are needed to implement and uphold Smart Maintenance. Furthermore, these capabilities must be trained effectively to ensure a qualified workforce for Smart Maintenance.

1.4 Research gap

As the Li-Ion battery industry is a relatively young industry, the combination of maintenance and training research is quite scarce. There is a research gap in empirical research in terms of case studies with actual empirical data gathered from the industry itself. This gap is what this thesis aims to bridge by providing first-hand empirical data in combination with existing research on maintenance, capabilities, and training.

1.5 Aim

The aim of this thesis is to develop an understanding of what human resources are necessary at Northvolt and their maintenance organization to become more data-driven and later fully utilize Smart Maintenance. There are three distinct goals within this aim. First, what human capabilities are necessary for a battery production maintenance organization. Second, how should new employees be trained to inherit these capabilities to ensure a skilled workforce. Third, create an effective step-by-step framework that can be repeatable for all areas of production.

1.6 Research Questions

The above problem formulation has been condensed to the three following research questions:

RQ1: What capabilities are needed for battery production maintenance roles to successfully implement Smart Maintenance?

RQ2: How should an overarching training structure be developed to ensure a qualified battery production maintenance technician workforce?

RQ3: What are the steps required to maintain and update competence requirements in a maintenance organization at a battery manufacturer?

1.7 Limitations

Due to time constraints, some limitations have been made. The focus level has been narrowed down twice to increase specificity and value creation. First, the thesis will only address one battery plant, Northvolt Ett in Skellefteå, Sweden. This is due to Ett currently being the only operational gigafactory in Sweden (Northvolt, 2023). Second, the scope was further refined to focus exclusively on maintenance within the area of Cell Assembly. The decision to use this level of abstraction, rather than examining the entire maintenance organization or focusing too narrowly on a specific role, ensures the results are as useful as possible for the industry. A

broader focus might render the results too general, while a narrower focus could limit their applicability and value. By limiting the scope, the unique characteristics and requirements of Cell Assembly can better be acknowledged.

Furthermore, the capabilities presented will be general due to the lack of specific knowledge of all technical requirements. Exactly defining what skills and knowledge should be included in mechanical, electrical, and chemical is too comprehensive to cover in this report. Additionally, this is independent of each production facility and product specification.

1.8 Structure of the thesis

- **Introduction:** Provides an overview of the report's objectives, background information, and the significance of the study.
- **Theoretical Framework:** Reviews literature and theoretical concepts relevant to the study.
- **Method:** Details the research design, data collection methods, and analysis techniques employed in the study.
- **Results:** Presents the findings from the empirical study made at Northvolt. This includes interviews and observations done at Northvolt Ett.
- **Creation:** Describes the development of new frameworks based on the results and insights gained from the theoretical framework and results. This chapter aims to answer the three research questions presented above.
- **Discussion:** Interprets the findings in a more general setting and discusses potential future research.
- **Conclusion:** Summarizes the main findings of the study.

2

Theoretical Framework

In the following chapter, the theoretical framework will be presented. The purpose is to describe concepts and theories regarding battery production, different maintenance policies, and training concepts. Lastly, the literature findings regarding relevant competencies for a digitalized industry will be presented in table 2.1.

2.1 Production systems

Production systems are fundamental to the manufacturing sector, serving as structured frameworks that guide the conversion of raw materials into finished products. These systems are comprised of three primary components: input, transformation, and output (Ju et al., 2015). The input element includes raw materials, labor, and information necessary to start the production process. Transformation is the core stage where these inputs are processed and altered to create the intended products, involving various technologies and methodologies specific to each industry. Finally, the output is the finished product, ready for distribution to consumers. According to the author, the ability of a production system to effectively integrate these components significantly influences the efficiency, quality, and profitability of the manufacturing process.

Historically, production systems have gone through three different paradigms, and currently, a fourth transition has begun (Kumar et al., 2020). These paradigms are characterized by the development of new technologies which improve the efficiency of production systems. The first era, Industry 1.0, known as the Industrial Revolution drastically changed manufacturing from heavily relying on manual labor to starting to utilize machines to increase production. Even if this era utilizes machines to increase production it is still characterized by low productivity and high variety in products. The subsequent era, Industry 2.0, continues to utilize machines and is mainly influenced by Henry Ford's development of the assembly line. This results in an era focused on low variation and high volume production. Industry 3.0 has been dominant since the introduction of computers. With new technology, customization of products was re-introduced with an additional focus on short delivery time (Har et al., 2022).

Industry 4.0, the era of advanced manufacturing, has seen significant development in production systems with the adoption of sophisticated technologies such as automation, digitalization, and data analytics (Ju et al., 2015). This shift towards

Industry 4.0 integrates digital data support systems, the Internet of Things (IoT), and cloud computing into the manufacturing process, significantly enhancing efficiency and product quality. These innovations facilitate real-time monitoring and control, enable predictive maintenance through IoT connectivity, and leverage cloud-based data analytics to optimize production flow and decision-making. This holistic integration results in smarter manufacturing environments that not only improve operational efficiency but also adapt dynamically to changing market demands.

Depending on the requirements of the production systems different set-ups exist. These vary, from high-volume low-variety to low-volume high-variety. The most common production set-ups are:

- **Project-Based Production:** Utilized in industries such as construction and shipbuilding, this system is tailored for unique, complex projects requiring a fixed position layout and a highly skilled workforce. It focuses on high variety, low volume, and high customization (Slack et al., 2022).
- **Job Shop Production:** Common in operations like tool manufacturing and jewelry making, this system is designed to produce many different products in small volumes. It uses a process-centered layout to manage complex flows with high variety but low volume (Slack et al., 2022).
- **Batch Production:** Employed in component manufacturing and bakeries, this system operates with middle volume and variety. It uses a cellular layout similar to job shop's, focusing on fewer products but higher volumes (Slack et al., 2022).
- **Line or Mass Production:** Typical in car manufacturing and food production, this system achieves high volume and low variety through a product-oriented layout. It is designed for mass production with minimal coordination required (Slack et al., 2022).
- **Continuous Processing:** Used in industries such as chemical and steel production, this system maintains high volume and very low variety with specialized, automated equipment. It supports a limited product range with continuous operation (Slack et al., 2022).

2.2 Battery manufacturing systems

Among the various types of production systems, battery manufacturing systems stand out due to their specific requirements for precision, safety, and environmental control (Rahimzei et al., 2018). First, the complexity of assembling electrodes, separators, and electrolytes in a confined space requires precision in manufacturing processes, making automation and advanced manufacturing techniques essential. Without adequate precision manufacturing the performance and safety of the battery will decline significantly. Second, due to the presence of hazardous chemicals and

high-voltage machines that could be dangerous if handled incorrectly, creating a safe work environment is of high importance within battery production. Lastly, battery production involves a highly controlled environment to handle materials sensitive to moisture and contaminants. Similar to high-precision manufacturing will failure in environmental condition heavily impact the performance and safety of the battery.

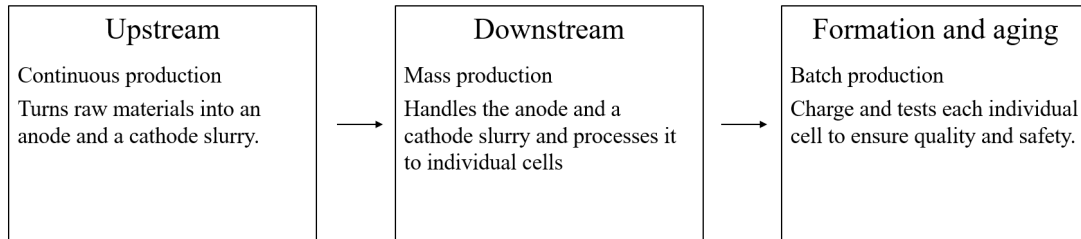


Figure 2.1: Overview of battery production.

Battery production systems typically involve three general steps including electrode manufacturing, Cell Assembly, and formation and aging, figure 2.1 (Rahimzei et al., 2018). These are known within Northvolt as upstream, downstream, and formation and aging. Each stage demands specific machinery and conditions to ensure product quality and safety. The first step, upstream, is characterized as a continuous production made out of large metal tubes mixing the different raw materials (Aydin et al., 2023). The raw materials are mixed into two different mixtures: an anode slurry, the negative side of the battery releasing electrons, and a cathode slurry, the positive side receiving electrons. The second step, downstream, turns the active material, anode and cathode slurry, into each individual cell by cutting and stacking it to the required sizes. This part of the production includes a clean and dry room environment, which requires lower particle and moisture content in the air (Ju et al., 2015). Cell Assembly is a subset of processes within downstream and the report’s main focus and therefore further described in the next section 2.3. Lastly, formation and aging include the initial charging cycle of the battery and several stress tests to ensure quality and safety standards are met. This requires precisely controlled electrical and thermal conditions.

The battery production system consists of three of the above-presented production types, continuous production, mass production, and batch production. Upstream, producing the slurry mix consists of continuous production as it is a continuous flow of active materials being mixed together (Aydin et al., 2023; Rahimzei et al., 2018). When this flow of active materials enters the Downstream production, the production system transform from flow production to mass production as the mix is divided into cells that are being line produced. In the final stage, formation and aging, the production system can yet again be said to change, from mass production to batch production. As cells are being prepared to be shipped to mass, they are divided into batches being shipped to customers or the.

2.3 Cell Assembly

This report will focus on the specific stage of Cell Assembly in battery production. According to Rahimzei et al. (2018), the Cell Assembly process for Li-ion batteries includes a sequence of precise steps that are important for the production of high-quality batteries. The process is critical as it determines the configuration and structural integrity of the cells, which directly impacts battery performance (Aydin et al., 2023).

2.3.1 Stages of Cell Assembly

The definition of Cell Assembly and what steps to include in Cell Assembly varies across literature and the industry. Cell Assembly is in this report defined based on the definition of Cell Assembly used at Northvolt and is presented below, figure 2.2. At Northvolt, prismatic cells are being produced, meaning that the cells are shaped as small squared boxes with a metal housing.

The Cell Assembly process can be broadly categorized into the following stages, each crucial for ensuring that the final battery cells meet quality standards:

1. **Assembly** The anode and cathode are wrapped and pressed tight to form the cells. In this stage, the nodes of the cathode are welded together, as well as the nodes of the anode are welded together (Rahimzei et al., 2018; Aydin et al., 2023).
2. **Packaging** In prismatic cells, the packaging involves securing the wrapped anode and cathode in an aluminum casing to provide structural support. The casing is then welded together (Rahimzei et al., 2018; Aydin et al., 2023).
3. **Electrolyte filling** The last step in Cell Assembly is electrolyte filling. This is one of the most critical processes in battery manufacturing, directly impacting the performance and safety of the battery. Rahimzei et al. (2018) and Aydin et al. (2023) explain that the electrolyte is filled under a vacuum using high-precision dosing needles. After filling, the cell is subjected to a pressure profile that ensures the electrolyte thoroughly wets the electrodes.

Throughout the assembly process, maintaining strict environmental controls is critical. Rahimzei et al. (2018) and Aydin et al. (2023) highlight that processes like electrode preparation and electrolyte filling require dry and clean rooms to prevent moisture contamination, which can degrade cell performance or create safety risks.

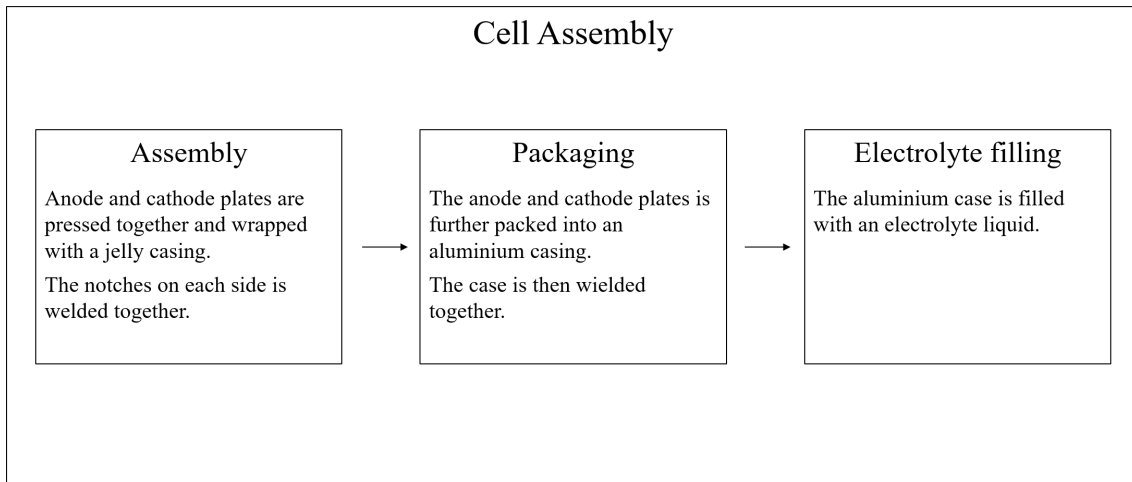


Figure 2.2: Overview of Cell Assembly.

2.4 Maintenance policies

Maintenance refers to the routine actions taken to keep machinery and equipment used in manufacturing in optimal working condition (Geurtsen et al., 2023). This process involves regular inspections, repairs, and replacements as needed to prevent breakdowns and ensure that production processes run efficiently and without interruption. The goal of production maintenance is to extend the lifespan of equipment, reduce downtime due to malfunctions, and maintain consistent production quality and output.

Different maintenance policies have been shaped over long periods of time to ensure optimal production systems. Each policy comes with its own pros and cons. Traditional maintenance policies have been used since the start of production systems and include run-to-failure maintenance, preventive maintenance, predictive maintenance, and condition-based maintenance (Mobley, 2002).

Run-to-failure maintenance is easily understandable as it is based on the logic that you only fix what is broken (Mobley, 2002). This is a reactive approach and can be described as less of a maintenance management approach as no proactive work is carried out. This approach is rarely used at its fullest as some preventive maintenance is carried out in combination with this approach.

Preventive maintenance includes different sub-policies determining the point in time in which maintenance will occur, for example, time-driven maintenance measures (Mobley, 2002). This approach carries out actions that are meant to prolong the lifespan of equipment by certain time intervals of running the equipment. Further, it can expand by implementing scheduled repairs and machinery adjustments for critical components to minimize downtime.

Predictive and condition-based maintenance differs from the previously presented

approaches (You, 2019). Through the development of sensors and equipment for measuring the state of machinery, maintenance can be scheduled based on the state and condition of the manufacturing equipment. This enables condition-based predictive maintenance. This approach uses data to anticipate the future state of machinery and determine when maintenance measures are needed. Predictive and condition-based maintenance facilitates planned stops in production which can limit the negative effects of the stops such as material destruction or safety risks.

As more data becomes available in factories, more data-driven maintenance concepts are being developed, one of which is Smart Maintenance (Bokrantz et al., 2020c). By utilizing data in a more advanced way through complex IoT and machine learning systems, Smart Maintenance can achieve even more effectiveness while having less impact on production. How the Smart Maintenance framework is defined is elaborated in the next section.

2.5 Smart Maintenance

This section will describe the concept of Smart Maintenance and define its constituents. The different maintenance management policies presented above are crucial to understanding the concept of Smart Maintenance and to fully understand how this new progressive way of looking at maintenance relates to the traditional approaches of maintenance tactics.

2.5.1 Defining Smart Maintenance

Smart maintenance is a concept defined by four dimensions: data-driven decision making, human capital resources, internal integration, and external integration (Bokrantz et al., 2020c). These dimensions outline an organizational design, specifically for structuring a maintenance organization within a data-driven manufacturing company, rather than a set of activities. The ground pillars in Smart Maintenance are four dimensions working simultaneously and the concept is not complete unless all four parts are fully functioning. The origin of Smart Maintenance can be derived from Industry 4.0 where advanced IT systems and data collection methods lead to large amounts of currently unused data. Figure 2.3 shows the concept of Smart Maintenance and how all dimensions need to be present to fully achieve it. This data can be analyzed through machine learning and artificial intelligence algorithms and function as a decision support system.

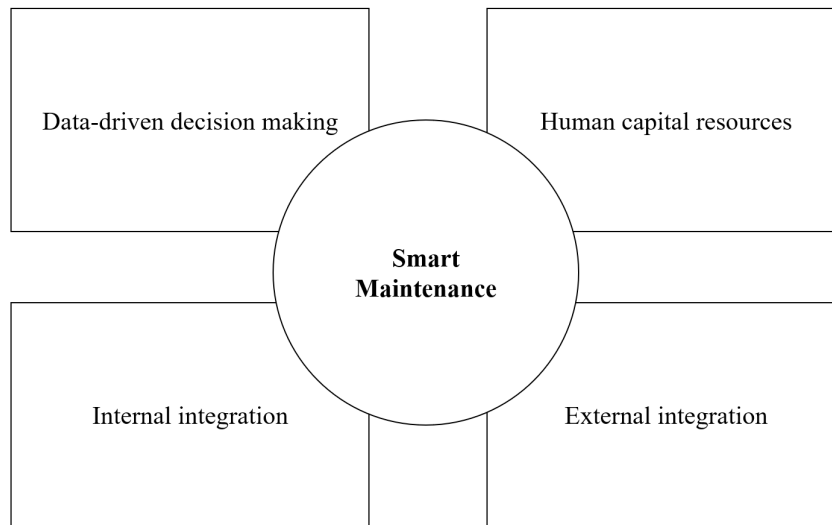


Figure 2.3: Smart maintenance defined by Bokrantz et al. (2020c).

Manufacturing facilities are constantly developing and getting smarter by the collection of more data. This has enabled the opportunity to make data-driven decisions, the first dimension of Smart Maintenance, instead of gut feeling or according to predetermined factors (Bokrantz et al., 2020c). By analyzing data collected from the manufacturing process using algorithms, machine learning, and artificial intelligence, it is possible to make maintenance decisions based entirely on information generated by the machines. The degree to which decisions are made based on data is therefore one of the cornerstones in Smart Maintenance.

Despite Smart Maintenance heavily relying on data-driven decision making, human capital, the second dimension, will still be a crucial part of maintenance in Industry 4.0 (Bokrantz et al., 2020c). However, the technological leaps taken in relation to Smart Maintenance parallel with new requirements for the maintenance employees. Skills related to analytics, information and communication technologies (ICT), adaptability, and technical performance will become more prominent in relation to maintenance personnel working with corrective maintenance. These newly highlighted requirements originate from the need to be able to interpret, analyze, and respond to the collected data.

Bokrantz et al. (2020c) describes the ability to integrate the maintenance function with other functions of the company, the third dimension, for example, production and the IT-department. Internal integration concerns the information flow between organizational functions and the maintenance organization. High internal integration could result in insights that reduce downtime and optimize assets. The more successful the implementation of internal integration, the more the chance of joint decision-making increases and the chance of favorable outcomes for all parties.

External integration, the fourth dimension, describes the interaction between the maintenance function and external entities, such as suppliers and partners (Bokrantz

et al., 2020c). By collaborating with external actors, the company can gain valuable insights from suppliers about the machines, thereby increasing operational efficiency. Additionally, sharing knowledge about their machines with suppliers can lead to updates and improvements that benefit the company in the long term. In conclusion, external integration enables the maintenance organization to leverage new innovations, access data, and acquire knowledge that extends beyond the company.

2.6 Related maintenance concepts

There are several other progressing maintenance theories relating to Smart Maintenance by exploring opportunities occurring due to Industry 4.0. Some of these data-driven approaches relating to Smart Maintenance are Maintenance 4.0, Asset Management, and Human Capital Management.

2.6.1 Maintenance 4.0

The concept of maintenance 4.0 is a product of the opportunities derived from Industry 4.0 (Benhamza Hlihel et al., 2024). Data collection in combination with advanced IoT systems allows for failure prediction, diagnostics, and maintenance program initiation which are closely connected to the theory of Smart Maintenance. The target of Maintenance 4.0 is to enable better performance of maintenance while minimizing workload through the help of data-driven decision making automation. The purpose of this is to facilitate intelligent handling of assets. The implications of maintenance 4.0 are likely to change the maintenance strategy from a run-to-failure system to a condition-based strategy where asset management is of greatest importance.

2.6.2 Asset management

Asset management encompasses a broad spectrum of activities aimed at maximizing the value of physical assets throughout their life cycle. It is not a pure maintenance policy but rather an overall company strategy. According to ISO (2014), International Organization for Standardization, asset management is a systematic process of developing, operating, maintaining, upgrading, and disposing of assets in the most cost-effective manner. This definition underscores the multifaceted nature of asset management, highlighting maintenance as a core component that impacts the entire life cycle of an asset.

Maintenance policies within the realm of asset management are diverse, including preventive, predictive, condition-based, and corrective maintenance (Schneider et al., 2006). These policies are not merely operational tasks but are strategic in nature, aimed at extending the asset's useful life, ensuring reliability, and minimizing downtime. The choice of maintenance policies is influenced by an asset's criticality, failure modes, and operational context. The author discusses how maintenance policies elaborate on how a strategic approach to maintenance can enhance asset reliability and performance while optimizing costs.

The relationship between asset management and maintenance is further explained by the concept of Total Cost of Ownership (TCO) (Park and Sharp, 2021). TCO considers all costs associated with the acquisition, operation, maintenance, and disposal of assets. Maintenance activities, therefore, play a critical role in influencing the overall cost-effectiveness and value realization of assets over their life cycle. Park and Sharp (2021) provides a comprehensive examination of the TCO model, highlighting the impact of maintenance on reducing life cycle costs and improving asset value.

Effective asset management requires a balance between operational efficiency, cost optimization, and risk management. Maintenance is pivotal in managing the risks associated with asset failure, which can have significant safety, operational, and financial implications. As noted by Kobbacy et al. (2008) and Park and Sharp (2021), maintenance is a key risk management tool that, when strategically applied, can mitigate the likelihood and consequences of asset failures.

This research focuses on Smart Maintenance as a maintenance concept when mapping capabilities for the maintenance organization. The reason is that Smart Maintenance is a concept incorporating various important aspects of maintenance. The four parts consisting of human capital resources, data-driven decision making, internal integration, and external integration create a comprehensible and encompassing understanding of how maintenance could be grasped. Other concepts like Maintenance 4.0 or Asset Management does not fully encompass all aspects that Smart Maintenance do. Therefore, Smart Maintenance is used as the focus maintenance concept in this report.

2.6.3 Human resource management

Human resource management (HRM) is the concept of managing the employees of the company to create a competitive advantage. Compared to physical assets which competitors can copy are human resources a unique set of assets to the company (Tiwari and Saxena, 2012). Effective human resources management increases adaptability and flexibility within the company due to a qualitative workforce. A qualitative workforce can develop new skills, create effective work processes, and handle a wide range of challenges if occurring (Khatri, 1999).

Similar to physical assets, human resources need investments to succeed however, compared to physical assets is the development of human resources harder (Tiwari and Saxena, 2012). Managing people requires more effort and the development is not as clear as investing in new processes or improved machinery. But firms able to improve their management of human resources compared to competitors can sustain an advantage longer compared to technological advancements (Tiwari and Saxena, 2012).

A sound HRM system typically involves multiple HRM practices, such as training, self-managed teams/teamwork, and information sharing (Pfeffer, 1994). These

practices help to develop a qualitative workforce and a supportive work environment for the continuous development of employees. However, according to Tiwari and Saxena (2012), there is no single list of practices for managing people; instead, effective HRM practices are highly dependent on the organization of the company, the industry in which it operates, and the competitive landscape.

The importance of managing human resources increases in Smart Maintenance (Bokrantz et al., 2020c) and Industry 4.0 (Hernandez-de Menendez et al., 2020). This is due to the new competencies required to succeed which is currently not existing within the workforce. Therefore is extensive investments in HRM necessary to develop training systems to up-skill current employees (Hernandez-de Menendez et al., 2020).

The article by Milewska and Gembalska-Kwiecień (2020) introduces competence matrices as a pivotal tool in optimizing production scheduling and forecasting human resource training requirements. By systematically identifying and aligning individual competencies with organizational needs, these matrices facilitate strategic human capital management, ensuring that workforce skills are effectively leveraged and developed to meet current and future demands. By systematically documenting employees' skills managers can ensure critical skills are met and necessary training is distributed to relevant personnel. This approach underscores the significance of dynamic human capital management in enhancing operational efficiency and competitive advantage.

2.7 Capabilities and competences

This report is focusing on one of the four Smart Maintenance dimensions, namely Human Capital Resources. The backbone of this dimension will be the capabilities that exist within the maintenance organization, paving a path for Smart Maintenance and its implementation. In this section, we will define the concept of capabilities and highlight those capabilities relevant to maintenance and Smart Maintenance.

The concept of capabilities pertains to human capability resources and is defined as 'the ability to do something' according to Cambridge Dictionary (2024a). This concept is closely related to skills and competence, as all three terms describe the execution of specific tasks and the effectiveness with which they are performed. Capabilities encompass a broader scope than competence; for instance, capabilities can refer to an organization's ability to perform a task, whereas competence is specific to an individual's ability.

In this context, the terms can be viewed hierarchically: capabilities are broader than competencies, which in turn consist of one or more skills. Thus, skills are a subset of competencies. This framework for understanding capabilities and competencies will be applied throughout this report and is illustrated in Figure 2.4.

Competence is used when describing an area of expertise or work such as process

engineer of battery production (Moore et al., 2002). This can be divided into three components; knowledge, values, and skills, that are necessary to achieve competence (Drisko, 2014). To fully achieve competence within an area, all three components must be fulfilled. This definition of competence is further strengthened by Cambridge Dictionary (2024b) as they define competence as “the ability to do something well”. Within the concept is skill seen as a key dimension and therefore further discussed below.

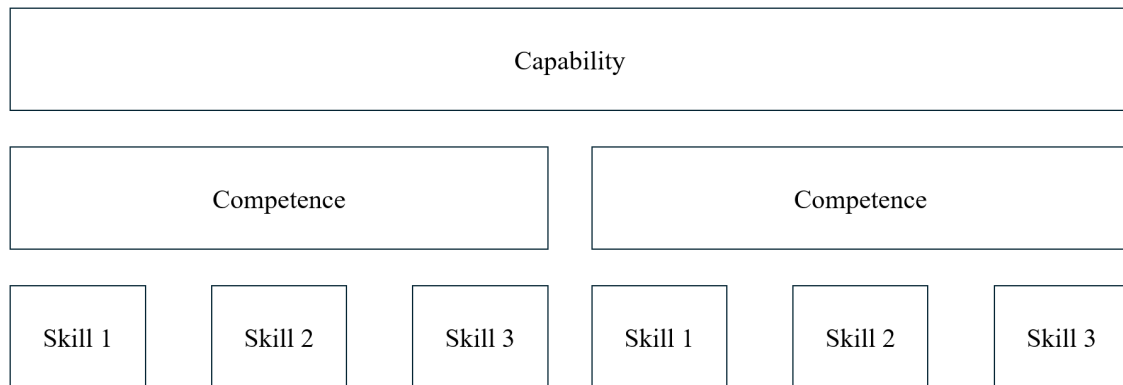


Figure 2.4: Overview of the hierarchy of capability, competence, and skill.

2.7.1 Skill

As mentioned above, skill is part of defining competence, which is an important concept for the thesis. Therefore, skill will be defined, and a distinction will be made between functional and interpersonal skills. A skill is defined as "an ability to do an activity or job well, especially because you have practiced it" (Cambridge Dictionary, 2023). This definition lacks the addition of knowledge and values underscore it being part of the concept of competence. Therefore, the only requirement to achieving a skill is to be able to perform it well without any underlying knowledge.

The term functional skills is used when referring to technical, tangible, and quantifiable abilities. Functional skills have been chosen as the name in this thesis but are often known in literature as hard skills. These skills are used to perform a specific job, or task, or handle certain equipment and require training or education to gain (Lyu and Liu, 2021). These skills are a necessity for industries as they allow for certain tasks to be performed with increased efficiency and safety (Lamri and Lubart, 2023). Due to this importance, businesses have incorporated functional skills tests, such as exercises performed in front of the interviewer, as part of their recruitment processes and as motivation in hiring decisions.

Interpersonal skills are the opposite of functional skills and refer to abilities that are not technical and thus harder to measure (Lamri and Lubart, 2023). In literature, these skills are often known as soft skills but within this thesis, they will be named as interpersonal skills. Included in the interpersonal skill concept are personal and interpersonal abilities essential for a sustainable work environment. Compared to

functional skills these are not usually practiced or trained but instead developed through self-reflection and self-improvement (Wisshak and Hochholding, 2020). This makes interpersonal skills more connected to each individuals' characteristics compared to functional skills.

2.7.2 Dividing capabilities

According to Wright et al. (2001) capabilities are often divided into two groups, general and firm-specific, in human resource management. In this report, capabilities will be divided into three different types, general, industry-specific, and firm-specific (Vang, 2002). A further separation between industry and firm-specific capabilities will be done in the thesis. This is done due to Northvolt's unique situation as a leading actor in Europe's battery production industry and therefore needs a deeper understanding of what capabilities are required to create in-house.

General capabilities are applicable for maintenance in most industries and could be taught or learned outside of both Northvolt as an organization and outside the battery industry (Wright et al., 2001). Industry-specific capabilities are unique to the battery sector and are typically acquired through education or training provided by institutions or organizations within the industry. Firm-specific capabilities are capabilities that must be taught directly in relation to the company, such as Northvolt, and cannot be expected to be found outside of the organization (Wright et al., 2001; Vang, 2002). This division of capabilities will be the foundation on which the training structure is built on. Generating general capabilities can be outsourced to other organizations, while the organization will have to ensure that industry-specific and firm-specific capabilities are created themselves.

2.7.3 Capabilities for maintenance

The literature identifies various capabilities essential for a maintenance organization. Below is a list of competencies identified in the reviewed literature, along with their respective sources:

Capability	Description	References
Ability to listen	The skill of attentively receiving and interpreting information to improve maintenance strategies.	Akyazi et al. (2022)
Adaptable and flexible	The capability to adjust to new tools, technologies, and processes in a dynamic environment.	Akyazi et al. (2022); Benhamza Hlihel et al. (2024); Jerman et al. (2020); Hernandez-de Menendez et al. (2020)

Analyzing skills	The ability to critically evaluate situations/problems to identify issues and their root causes.	Benhamza Hlihel et al. (2024); Institute (2014); European Skills/Competences, Qualifications and Occupations (ESCO) (2024)
Asset management capability	The competence of managing equipment and resources to optimize maintenance schedules, operations, and asset values.	Swanson (2001); Benhamza Hlihel et al. (2024); Jooste et al. (2020); Institute (2014)
Calm mentality	The ability to remain composed in stressful situations to ensure effective problem-solving.	Benhamza Hlihel et al. (2024); Bengtsson and Berglund (2024)
Chemical competence	Understanding of how to safely handle and use chemicals for the production of batteries.	Rahimzei et al. (2018)
Clean and dry rooms	Knowledge of how to work in controlled environments to prevent contamination in battery production.	Rahimzei et al. (2018)
Communication skills	The ability to convey information effectively between different parties to ensure smooth maintenance operations.	Bokrantz et al. (2020a); Benhamza Hlihel et al. (2024); Institute (2014); Akyazi et al. (2022)
Critical thinking	The skill to evaluate situations and risks swiftly to make informed decisions under pressure.	Akyazi et al. (2022); Benhamza Hlihel et al. (2024); Kipper et al. (2021)
Data analytics skills	The ability to analyze complex data sets and extract actionable insights.	Bengtsson and Berglund (2024); Benhamza Hlihel et al. (2022); Institute (2014)

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Decision making	The ability to make prompt, accurate decisions in situations to maximize outcome.	Benhamza Hliheli et al. (2024); Emmanouilidis et al. (2011); Bengtsson and Berglund (2024); Hernandez-de Menendez et al. (2020); Institute (2014)
Delegation	Assigning maintenance tasks to team members based on their skills, experience, and current workload to optimize resource use.	Benhamza Hliheli et al. (2024)
Digital tool understanding	The ability to use and understand digital tools integral to modern machinery and maintenance.	Jooste et al. (2020); Kipper et al. (2021); Benhamza Hliheli et al. (2024); Akyazi et al. (2022)
Electrical competence	Knowledge of electrical systems and components used in modern manufacturing.	Rahimzei et al. (2018); Zahiraldinni (2022); Bengtsson and Berglund (2024); Akyazi et al. (2022); Benhamza Hliheli et al. (2024); Institute (2014)
Escalation	The competence to evaluate maintenance issues and to raise it to higher competence/authorities when normal procedures are inadequate to prevent downtime or damage.	Benhamza Hliheli et al. (2024)
Interdisciplinary thinking	The ability to integrate knowledge from different domains to enhance decision-making.	Jooste et al. (2020); Kipper et al. (2021)
Language skills	Proficiency to communicate clearly across different levels of the organization and to receive information without misinterpretation caused by language barriers for safe and efficient maintenance.	Hernandez-de Menendez et al. (2020); Benhamza Hliheli et al. (2024); Akyazi et al. (2022); Institute (2014)
Maintenance understanding	Knowledge of maintenance methodologies and best practices to optimize equipment reliability.	Akyazi et al. (2022); Benhamza Hliheli et al. (2024)

Machinery knowledge	Understanding of the operation and maintenance of advanced machinery used in the battery manufacturing industry.	Rahimzei et al. (2018)
Mechanical competence	Proficiency in understanding and maintaining the mechanical aspects of production equipment.	Rahimzei et al. (2018); Zahiraldinni (2022); Bengtsson and Berglund (2024); Akyazi et al. (2022); Benhamza Hlihel et al. (2024); Institute (2014)
Personal drive	The initiative to proactively find solutions and take responsibility for one's work.	Hernandez-de Menendez et al. (2020)
Personnel management	Managing maintenance team members and ensuring their efficiency and safety.	Akyazi et al. (2022); Institute (2014)
Planning	Scheduling and organizing maintenance activities to ensure efficient operations without interrupting production.	Akyazi et al. (2022); Institute (2014)
Presentation skills	The ability to articulate strategic goals and technical information effectively to various audiences.	Benhamza Hlihel et al. (2024); Institute (2014)
Preventive and predictive maintenance	The ability to use data and tools to anticipate and prevent equipment failures and to plan maintenance accordingly.	Bokrantz et al. (2020b); Liu et al. (2019); Akyazi et al. (2022); Institute (2014)
Prioritization skills	The ability to manage the maintenance organization to prioritize maintenance tasks dependent on constraints relating to time, resources, and criticality efficiently by focusing on high-priority tasks.	Zahiraldinni (2022)
Process understanding	Comprehension of operational workflows and machinery systems to effectively diagnose issues and optimize maintenance.	Akyazi et al. (2022); Jooste et al. (2020); Benhamza Hlihel et al. (2024)
Project management	Capabilities in planning, executing, and finalizing maintenance projects to meet deadlines and budgets.	Akyazi et al. (2022); Institute (2014)

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Reporting and documentation	The competence to maintain detailed maintenance records for knowledge sharing and improvement.	Akyazi et al. (2022); Institute (2014); Benhamza Hlihel et al. (2024)
Risk management capability	Competence to identify potential risks and implement measures to prevent failures in maintenance.	Akyazi et al. (2022); Jooste et al. (2020); Institute (2014)
Self-learning	The drive to continuously improve skills and adapt to new technologies in the maintenance field.	Akyazi et al. (2022); Benhamza Hlihel et al. (2024); Emmanouilidis et al. (2011); Hernandez-de Menendez et al. (2020)
Teamwork	The ability to collaborate efficiently with colleagues to achieve common goals.	Akyazi et al. (2022); Benhamza Hlihel et al. (2024)
Teaching and training	The competence to effectively transfer knowledge and train others in maintenance best practices.	Hernandez-de Menendez et al. (2020); Akyazi et al. (2022); Jooste et al. (2020); Benhamza Hlihel et al. (2024)
Time management	The competence to efficiently manage one's own time, prioritizing and organizing tasks to ensure that maintenance activities are completed within operational windows.	Benhamza Hlihel et al. (2024); Institute (2014)
Troubleshooting skills	The ability to identify and resolve issues quickly to solve problems and their cause.	Hernandez-de Menendez et al. (2020); Bengtsson and Berglund (2024)
Work methods	The ability to follow standardized procedures ensure safe, efficient, and consistent maintenance work.	Akyazi et al. (2022); Benhamza Hlihel et al. (2024)

Table 2.1: Capabilities found in the literature relevant for battery production maintenance.

2.8 Existing capability mapping for battery maintenance

The amount of research published relating to maintenance within battery maintenance is limited. Some organizations have attempted to map the capabilities required for various roles in battery maintenance. Their goal is to contribute to green energy and facilitate the transition in Europe by providing essential skills for effective training and creating a platform for stakeholders to connect (Project ALBATTTS, 2023a). The ALBATTTS project (Alliance for Batteries Technology) has created multiple skill cards which includes definitions and necessary skills for positions within battery production. The battery production maintenance technician, according to ALBATTTS, maintains and repairs battery production equipment in manufacturing plants. They ensure machinery operates efficiently and are skilled in mechanical, electrical, and control systems (Project ALBATTTS, 2023c). Further, the role of battery production maintenance engineer is described as someone who ensures efficient operation of machinery in battery manufacturing plants. Skilled in mechanical, electrical, and control systems, they handle maintenance, repairs, and troubleshooting, while adhering to safety standards. Their responsibilities include conducting inspections, resolving production issues, and collaborating with staff to maintain production schedules and quality. They also keep detailed maintenance records and train staff on equipment usage (Project ALBATTTS, 2023b).

2.9 Training

Identifying, developing, and sustaining the required capabilities can be a challenge for many industries, including battery manufacturing. This underscores the need for effective training frameworks and strategies. This section presents various training approaches for production industry settings.

2.9.1 Training Within Industry

Training Within Industry (TWI), is a structure originating from the US to increase production of multiple industries rapidly during World War II (Dinero, 2010). The system was a joint effort between the government, industry leaders, teachers, and psychologists who recognized the importance of training systems. Training systems allow companies and industries to help themselves in the future as they continuously develop competent employees. By educating managers or supervisors the right way they can distribute their knowledge throughout the organization and thus create a competent workforce.

In TWI, supervisors are seen as key players in the organization as this is the position between the workers and upper management (Dinero, 2010). Well-performing supervisors are a big reason for improved production and TWI recognizes five needs that must be fulfilled for every supervisor. If all needs are fulfilled supervisors can successfully educate workers and improve methods currently used. These five needs

recognized in TWI are:

- Knowledge of work
- Knowledge of responsibilities
- Skill in instruction
- Skill in improving methods
- Skill in leading

Knowledge is defined by TWI as something you have or not, you either know the facts or you don't. Skills on the other hand is the ability to perform a task at a satisfactory level which needs practice to achieve (Dinero, 2010). To develop the necessary skills each supervisor must undergo a three-part training program also known as the "J programs". The first program "Job Instruction Training" educates the supervisor in how to perform instructions for other workers. This is done by understanding on how to break a job down and teach individual parts. The second program "Job Methods Training" focuses on how to improve current methods. The last program "Job Relation Training" teaches the individual how to develop their own and other's relationships within the company and other stakeholders. This is mainly focused on employees with some managerial responsibilities. After completion of the J programs and sufficient knowledge is acquired, supervisors should be able to educate new and current workers in correct work methods while having the ability to improve methods which is not up to par.

2.9.2 Learning Factories

Kipper et al. (2021) and Laboissiere and Mourshed (2017) argue that "Learning Factories" are the most effective system for developing competent employees. Both articles emphasizes on the opportunity to utilizes the theoretical knowledge gained to develop into practical skills. Learning factories are specialized educational environments that replicate real-world production settings, providing hands-on training that combines theory with practice. They enable participants to engage directly with industrial processes in a controlled yet realistic setting (Abele and et al., 2017; Romero and et al., 2019). Learning factories emphasize practical experience, allowing trainees to refine their problem-solving and creativity in manufacturing scenarios that require quick adaptability and self-organization.

While learning factories offer substantial benefits, such as developing industry-relevant skills and fostering innovation, learning factories also face challenges (Alves and et al., 2017). They require significant investment in equipment and facilities, making setup and operational costs high. Further, their scalability is limited due to resource constraints and the need for specialized personnel to ensure effective training, leading to limitations to the learning factory setting (Alves and et al., 2017).

2.9.3 Spaced repetition and multifaceted training

According to Ibrahim et al. (2017) spaced repetition leads to increased learning and retention of knowledge for a longer period compared to information and skills only taught or practiced once. This allows the information to internalize between repetitions which speeds up knowledge gains. Further, Ibrahim et al. (2017); Uslu et al. (2021); Elnaga and Imran (2013) presents findings that demonstrate the superiority of multifaceted training over single-faceted training in enhancing learning outcomes. Multifaceted training enables participants to acquire knowledge through various sources, including auditory, visual, and hands-on exercises.

2.9.4 High intense or low intense training

Differences can be found between Ibrahim et al. (2017) who showed increased learning when programs were extended over a longer period and Uslu et al. (2021) who highlighted short intense periods as most effective. According to Ibrahim et al. (2017) the longer period allows for increased repetition and spaces where workers can internalize the new knowledge. Uslu et al. (2021) on the other hand found results showcasing short periods of effectiveness due to workers' ability to only stay highly motivated for a short period of time. Dinero (2010) describes the TWI program as a combination of both, people are only able to intake a small amount of information at a time without information overload. To avoid this should training be done through frequent but short sessions.

2.9.5 Positive effects of training

Efficient and structured training is found to serve a dual purpose, benefiting individual employees as well as the larger organizational structures, such as teams and work shifts (Elnaga and Imran, 2013). Moreover, the implementation of effective training programs has been observed to increase the retention of skilled employees by increasing their motivation. This increase in motivation is attributable to the perceived commitment of the company to its workforce's development and well-being. According to Elnaga and Imran (2013), efficient training programs develop not only the knowledge of the workforce but also the willingness for organizational change. These factors help the organization to achieve continuous competitive advantage. Conversely, a significant motivator for employees to switch employers is the inability to effectively perform the tasks required of them, which underscores the importance of adequate training initiatives.

According to Uslu et al. (2021) other positive effects of efficient training is seen when opportunities for feedback are integrated. Feedback allows training and trainers to improve existing and develop new programs. Furthermore, the opportunity to give feedback also positively affects the perception of the training increasing its effectiveness. Group-based training is shown to not only increase knowledge acquisition between group members but also promote teamwork. Similar effects are found in training performed on-site compared to training through the web. However, web-based training has the advantage of allowing people to undergo them whenever and

wherever they are, this is shown to give positive results for some types of training focused on knowledge and not skills (Laboissiere and Mourshed, 2017).

2.9.6 Maintenance roles in battery production

The maintenance organization at Northvolt consists of mainly five different types of roles. The roles are technicians, supervisors, planners, managers, and engineers. Each role serves a different purpose within the maintenance organization and consists of different tasks and job descriptions. All roles described in the report is general and targeted towards battery production maintenance and therefore do not execute any maintenance on individual battery cells.

Maintenance Technician: Maintenance technicians are on the front lines, directly handling the maintenance and repair of equipment. Their primary duties include performing routine inspections, diagnosing mechanical issues, and executing minor repairs to ensure uninterrupted production. They are also responsible for performing preventive maintenance tasks, such as cleaning and lubricating machinery, to minimize the likelihood of equipment breakdowns (Society for Maintenance & Reliability Professionals (SMRP), 2022).

Maintenance Supervisor: The maintenance supervisor manages the daily activities of the maintenance team. They allocate tasks, manage schedules, and ensure compliance with safety protocols. Their role includes overseeing the performance of technicians, coordinating preventive maintenance activities, and acting as a bridge between the maintenance team and higher management. This ensures that the team is working effectively and that maintenance issues are promptly addressed (Society for Maintenance & Reliability Professionals (SMRP), 2022).

Maintenance Planner: Maintenance planners play a crucial role in optimizing the maintenance process. They are responsible for planning all maintenance activities to ensure the smooth operation of battery production facilities. They develop detailed maintenance plans, schedule preventive maintenance, and coordinate downtime together with the production organization, and allocate resources to maximize efficiency. They also maintain accurate records of maintenance activities, monitor spare parts inventory, and ensure that maintenance work aligns with production goals (Ekberg and Kabo, 2022).

Maintenance Manager: Maintenance managers take a strategic approach to ensure the reliability and efficiency of equipment in battery production. They develop and implement comprehensive maintenance strategies, manage budgets, and oversee the maintenance team's performance. They focus on optimizing equipment up-time, and ensuring compliance with safety regulations. Additionally, they coordinate closely with production and engineering teams to align maintenance activities with broader production objectives (Ekberg and Kabo, 2022).

Maintenance Engineer: Maintenance engineers focus on analyzing equipment

performance and developing strategies to enhance equipment reliability in battery production. They design and implement improvements to maintenance processes together with the asset management team, develop preventive maintenance strategies, and work on reducing equipment downtime. Their expertise is crucial in troubleshooting complex issues, guiding maintenance technicians, and ensuring the effective use of advanced diagnostic tools and technologies (Ekberg and Kabo, 2022).

In this article, the different positions will be divided into the two categories blue-collar workers and white-collar workers. Blue-collar workers include maintenance technicians while white-collar workers are supervisors, planners, managers, and engineers.

3

Methods

In this chapter, the method of the research will be presented which includes abductive reasoning, the approach and design of the research, and how different activities will be carried out.

3.1 Abductive reasoning

Research studies are based on one of three approaches, deductive, inductive, or abductive (Bell et al., 2019). A deductive study is based on testing a predetermined hypothesis or theory to either confirm it or reject it through observations or experiments. An inductive study is not based on a preconceived theory but rather derives patterns, regularities, and theories from observations and data collection. Abductive studies are often used to formulate hypotheses to test by investigating incomplete sets of observations and derive a likely explanation from these explanations.

Throughout this report, an abductive approach has been used, as this report has been conducted with the aim of exploring what capabilities are necessary for Northvolt to succeed with Smart Maintenance. This has allowed the study to change between empirical gathering and literature reading to guide the research further based on relevant findings (Yom, 2015).

3.2 Research approach

The research strategy used in this study is a combination of a case study, which involves an in-depth investigation of a single case, and a thematic analysis (Creswell and Poth, 2016). Thematic analysis will be used to analyze the data gathered, as it is suited to exploring complex phenomena where the boundaries between context and issue are not clearly defined. It allows for an extensive examination of the data within specific environments, leading to an understanding of the subject matter. Case studies are beneficial for generating insights into the processes and outcomes of a situation, facilitating the development of hypotheses for further testing. Furthermore, the thematic analysis will enable finding conclusions and takeaways by combining findings from literature as well as empirical data (Creswell and Poth, 2016; Bell et al., 2019).

To understand what necessary human capabilities resources are needed to implement and maintain Smart Maintenance in battery production the maintenance organiza-

tion of Northvolt Ett has been used. This setting is used to create the bounded system where in-depth data gathering has been made through interviews and observations. A case study combined with additional literature readings provides a unique possibility by mixing knowledge from people relevant to the case and the research community to create valuable conclusions and guidelines for future research.

3.3 Research design

This study has been conducted through three phases. The three phases have been used to conduct the study and important steps to formulate comprehensive conclusions for each research question presented in the introduction. Each step has been an iterative process where new knowledge and insights have led to new directions that formed how the work was conducted in the subsequent steps. The three steps were conducted in sequence, however, with some overlaps between the steps due to time efficiency aspects.

3.3.1 Phase one

The purpose of the first phase was to gain knowledge that creates a foundation for the study, following the proposed structure of Bell et al. (2019). This phase consisted of two parts, unstructured interviews at Northvolt and general literature readings in relevant areas. To gain a deeper knowledge about Northvolt and the maintenance organization unstructured interviews were used. This was done in conjunction with the first visit to the Northvolt Ett factory in Skellefteå and included personnel from several areas including the maintenance and training department. Simultaneously the general literature study was conducted to create a foundation of understanding for relevant subjects.

The literature search was designed to be extensive and aimed at encompassing a wide range of perspectives relevant to the project. Subjects included in the general literature study were: smart maintenance, battery production, maintenance strategies, capability mapping, and competence development. This approach was essential for establishing a foundation, which was crucial to achieving accuracy and depth in subsequent stages of the study. A more in-depth description of the literature study is found in section 3.4.

3.3.2 Phase two

The second phase continued on the first but narrowed the focus to only include data gathering connected to the research questions. Yom (2015) describes this stage as the first iteration of data collection where general data is evaluated and either discarded or accepted for further investigation. The iterative process of revisiting both interviews and literature is necessary to form grounded and internally robust explanations in abductive research.

In this phase, the area of interest, Cell Assembly, was chosen together with relevant

positions within the organization to contact for interviews. The choice to use Cell Assembly as a research area was mainly motivated by the current process of creating capability matrices for the maintenance organization. This phase continued to include both interviews and literature research. However, in contrast to the earlier stage, this second phase used semi-structured interviews and a more structured literature research. Semi-structured interviews were used as they provided a direction for the interviews without hindering new findings based on the answers from interviewees. Similarly, the literature review was more structured, and areas highly relevant to the research questions were further reviewed.

3.3.3 Phase three

The final phase utilized the data and information gained from the two previous phases to formulate answers to each research question presented in section 1.6 (Yom, 2015). This includes defining and presenting relevant capabilities for different positions within the maintenance organization, creating an overarching training structure for new and current employees, and a repeatable method to perform in other areas of battery production.

Relevant human resource capabilities for different maintenance roles required to implement and maintain Smart Maintenance were found and defined through a combination of literature research and interviews. To increase the reliability of the conclusion, iterative feedback interviews with relevant personnel were used. The framework formulation process was continuously reevaluated through both literature analyses and interviews where personnel at Northvolt shared opinions and highlighted strengths and weaknesses with the proposed framework. This allowed altering the framework and finding a more suitable solution. Lastly, the method proposed to recreate the results on other parts of battery production is based on the systematic approach of this study with case-specific learnings made through the research.

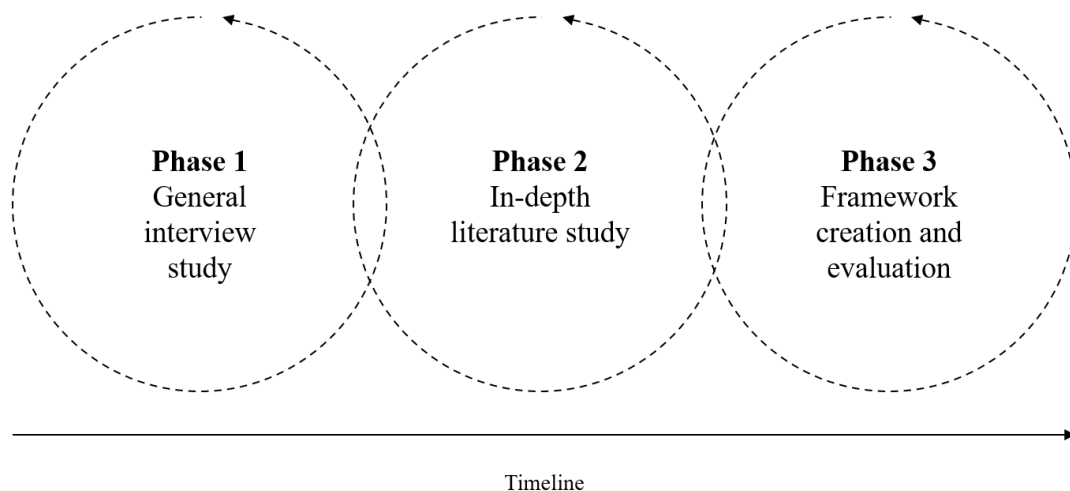


Figure 3.1: Visual presentation of the method used in this study.

3.4 Literature study

A literature study was performed to complement the empirical research with both general and specific knowledge within key areas such as different maintenance policies, competence mapping, and personnel training. It aims to summarize and evaluate a set of knowledge within a subject. The knowledge gained is used to formulate theoretical frameworks and appropriate methods used in the research project. According to Knopf (2006), there are four key pointers for conducting a literature review. First, each article should be summarized by its main points, even if it is not directly used in the research report. Second, the literature review should be selective, ensuring that every article brings value and maintains its validity. Third, rather than merely listing each article, the review should group them into "schools of thought" that offer different perspectives or theoretical frameworks relevant to the report. Finally, while other summaries can be useful for identifying potential articles, they should not replace the actual reading of the article itself.

The literature search was not limited to only articles related to battery production but extended to other types of industrial maintenance as well. The reasoning for this is due to two factors, the relatively small volume of research done in battery maintenance and the knowledge existing in other industries that could be used in a battery setting. As the literature research was divided into two parts following the structure of the research with an initial general part, followed by a second specific part. Table 3.1 shows the field of literature search for the initial part and table 3.2 shows the field of literature search for the second part. The tables include databases used and specifications of search terms used in combination with the field of search.

As stated above is literature based on other industries than the battery manufacturing industry used, this creates a low level of uncertainty regarding its validity. Training Within Industry, described in section 2.9.1, is not developed to create an efficient battery industry but developed to be applicable to a wide range of industries. Similarly, existing competence mapping for production maintenance is primarily made in other industries. Therefore the combination of theoretical findings, presented in chapter 2, together with empirical findings, presented in chapter 4, is critical. Empirical findings are able to validate theoretical findings while the theoretical findings are able to add new perspectives which potentially increases the value-adding of the report to Northvolt and the research field.

Field	Databases	Detail
Training	Web Of Science, Google Scholar	Training within industry, training in manufacturing, skill decline, up-skilling, knowledge transfer
Data driven decision making	Web Of Science, Google Scholar, Scopus	AI capabilities, data driven decision industry
Human capabilities battery industry	Web Of Science, Google Scholar, Scopus	Human resources, capabilities battery industry
Types of competencies	Web Of Science, Google Scholar, Scopus	Competencies human resources, Competencies industry

Table 3.1: Overview of research fields and details for the first literature research.

Field	Databases	Detail
Competence mapping	Web Of Science, Google Scholar, Scopus	Competence mapping automotive industry, competence matrix, competencies, European competency database
Capability mapping	Web Of Science, Google Scholar, Scopus	Capabilities maintenance, capabilities Industry 4.0
Battery industry	Web Of Science, Google Scholar, Scopus	Li-ion battery production, Cell Assembly
Maintenance	Web Of Science, Google Scholar, Scopus	Maintenance methodology, maintenance in industry
Smart Maintenance	Web Of Science, Google Scholar, Scopus	Maintenance 4.0, predictive maintenance, condition-based maintenance

Table 3.2: Overview of Research Fields and Details for the second literature research.

3.5 Interviews

Interviews were utilized as a primary method in this study to gather in-depth insights that were not accessible through published articles. The participants included

individuals involved in maintenance, staff education, and operations, all of whom play critical roles in impacting the efficiency of maintenance practices within the organization. To ensure the accuracy and completeness of the data collected, all interviews were either recorded and transcribed or noted down during the interview if preferred by the interviewee. This method enabled the capture of nuanced perspectives and experiences, contributing significantly to the results of the research findings.

According to Bell et al. (2019), interviews are divided into two groups: structured and unstructured. A structured interview is usually done through a survey with closed-ended questions to limit possible answers. Closed-ended questions are used to minimize variation in answers due to misinterpretation from the interviewee. This makes structured interviews a good tool for gathering comparable data from a large group of people (Bell et al., 2019).

Unstructured interviews, on the other hand, are less suitable for large groups and utilize more open-ended questions to let the interviewee lead where to go (Bell et al., 2019). These types of interviews are often divided into semi-structured and unstructured interviews. Unstructured interviews are performed with only a few prompts or initiating questions to set a direction for the interviewee. Semi-structured interviews could include both open- and closed-ended questions to let each interview be different depending on the interviewee. The interview guide was used to reduce variation between interviews but not restrict the interviewee when answering (Bell et al., 2019).

This project only includes unstructured and semi-structured interviews to maximize the knowledge sharing from each interviewee. Interviews were conducted in two phases where the first one focused on gathering more general information and the second phase a more in-depth perspective. This was done to utilize the learnings from the first round of interviews to create valuable questions used in the second round. Thus, the first phase was performed unstructured with only a few questions to give the interviewee a direction. The second phase was semi-structured with pre-planned open-ended questions with room for alterations depending on the answers of the interviewee. In total, 21 interviews were conducted with a length ranging from 30 to 60 minutes.

3.6 Data analysis

As mentioned above in section 3.2 the approach used was a combination of thematic analysis and a case study. Based on the principles of thematic analysis, data was collected, and hypothesis creation was an iterative process shaping each other (Bell et al., 2019). To create this iterative process between data gathering and hypothesis creation a structured coding method was used to categorize qualitative data gathered. In this study, coding involved identifying patterns and categories from the data collected through literature and interviews (Bell et al., 2019). Figure 3.2 describes the coding processes where individual findings from both literature and

interviews were assigned a category. These categories were used to compare findings to identify patterns from all the sources.

This data coding occurred until a saturation point was reached, where no new concepts or categories emerged from the data, indicating that further fragmentation of the data would not yield additional insights. The coding process was iterative, involving constant comparison where newly formed concepts were continuously compared against the collected data. This method ensured that the results were firmly grounded in the empirical data. To effectively link empirical findings with insights from the literature, a detailed coding structure was developed. This structure allowed for the systematic mapping of insights found from the literature review and aligning them with the codes derived from empirical analysis. Each literary finding was methodically associated with these predefined codes, ensuring a comprehensive integration of diverse perspectives. Figure 3.2 visualizes the relationship between empirical findings and literature findings.

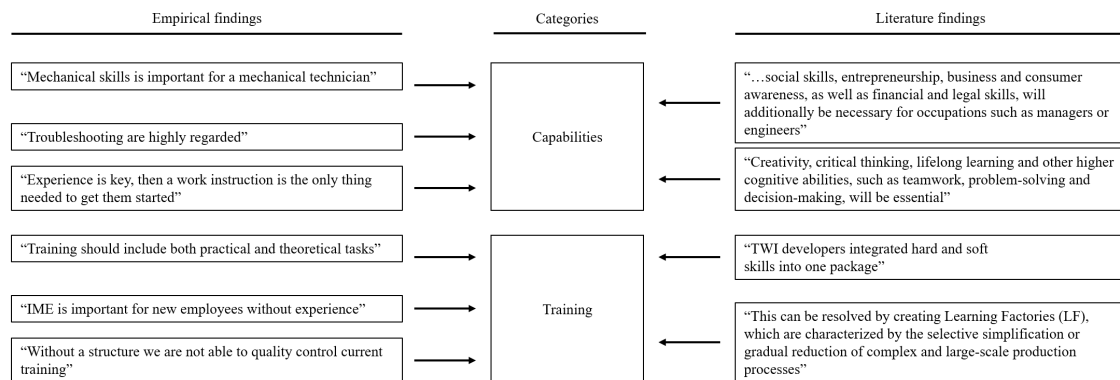


Figure 3.2: Coding structure for data gathered from interviews and literature.

3.7 Usage of generative AI tools

This report has utilized generative AI tools to enhance the clarity, coherence, and readability of the text originally written by the author. However, it is important to note that these AI tools were not used to generate any original content or create new text. All ideas, analyses, and written content were authored by the report’s writer, with AI assistance serving only to refine and polish the language.

4

Results

This chapter presents only the findings of the empirical study including interviews and observations made at Northvolt Ett. The results are divided into three areas: competencies, training, and work process. Each section will end with key insights that summarize the most important findings.

4.1 Competences

Results from interviews regarding important competencies are presented in this section. All participants were asked about competencies and skills necessary to succeed at Northvolt today and reflect on what is needed when Smart Maintenance is implemented in the coming years, the questionnaires used are presented in Appendix A. The result is divided into three parts where the first section presents the results regarding the importance of previous experience and the subsequent sections are focused on blue- and white-collar employees.

4.1.1 Mechanical and maintenance experience

Several interviewees highlighted the importance of mechanical and maintenance experience when joining as new employees. For technicians, this increased their learning rate and quality of performing maintenance tasks. Supervisors, planners, engineers, and managers are instead able to do their tasks better through a deeper understanding of how maintenance is performed. Thus, previous experience is found to be important regardless of position within the maintenance organization.

"I understand the problems better because of my experience as a technician and therefore able to work on improvements."

Results from the interviews indicate that experienced personnel are a key asset in operational efficiency. Their familiarity with the work environment enables them to operate independently from existing work instructions, thus reducing the need for training and the reliance on specific guidelines. This competence is particularly valuable in scenarios where rapid scaling is necessary, as in the case of Northvolt, these individuals demonstrate a robust capacity to manage diverse tasks and contribute to value creation directly.

"Need to have some technical background and it is good if you have worked with maintenance or at least in some kind of factory. The reason is that you are able to learn everything faster if you have relevant experience."

Moreover, the role of experienced workers extends beyond their immediate responsibilities. They are identified as critical actors in the transfer of knowledge within the organization. This is especially notable in the continuity of operations between shifts. Interviewees highlight that experienced personnel also play an important part in teaching and mentoring their less experienced counterparts, thus ensuring that expertise and best practices are consistently spread across the workforce.

"There are no dedicated system for communicating between shifts and therefore are experienced personnel important as they are good with this type of communication."

Key Insights - Mechanical and maintenance experience

- **Role-Wide importance of experience:** Experience enhances performance across all maintenance roles, improving task quality and operational understanding.
- **Efficiency and independence:** Experienced personnel boost operational efficiency by working independently, reducing the need for detailed work instructions and extensive training.
- **Knowledge transfer:** Experienced workers are crucial for spreading best practices throughout the organization, enhancing continuity and expertise across shifts.

4.1.2 Blue-collar in Smart Maintenance

In the thesis, the term "blue-collar" is used as it refers to jobs primarily involving manual labor. Specifically, maintenance technicians, detailed in section 2.9.6, are classified as blue-collar workers due to the manual nature of their primary tasks. The interviews conducted with blue-collar workers reveal a consensus regarding the nature of their work: the core responsibility lies in the repair and maintenance of machinery, a task that has remained consistent for decades. Despite this consistency, there has been a noted increase in the complexity of both the machinery in question and the tools required for maintenance. Interviewees from several positions project that the fundamental role of a technician in maintenance will persist with little variation in the future.

Through the interviews, several capabilities required by blue-collar workers were identified. These capabilities include:

- Analyzing competence
- Communication skills
- Maintenance understanding

- Troubleshooting
- Interdisciplinary thinking
- Language skills
- Teamwork
- Continuous learning
- Calm mentality
- Personal drive
- Open minded
- Mechanical competence
- Electrical competence
- Chemical competence
- Clean and dry room
- Understanding of digital tools
- Machine knowledge
- Safety procedures
- Work methods including documentation and reporting
- Product knowledge
- Teaching and training

Mechanical, electrical, and chemical knowledge is seen as key skills for all technicians and essential to be able to carry out tasks. Machines and production technology will develop further but a basic knowledge in these areas will allow employees to develop the necessary specific knowledge at a fast pace. The understanding of how to work within clean and dry rooms is an industry-specific requirement that exists today and will not change for Smart Maintenance. Thus, functional skills important today are believed to remain important even after Smart Maintenance becomes a reality. Further, while traditional competencies such as mechanical and electrical knowledge continue to be valued, there is an emergent need for adaptability and a willingness to engage with new processes and methodologies due to Northvolt's current expansion and construction of facilities. This reflects a broader trend towards continuous learning and flexibility within the workforce.

"It's important to have basic mechanical, electrical, and chemical knowledge, if maintenance technicians have this knowledge they know when to call for specialists which could end up save someone's life"

Due to smart maintenance, the understanding of digital tools will increase in importance as mechanical failures can be avoided through digital analysis and adjustments. However, interviewees do not foresee an expansion of the maintenance technician roles to encompass extensive data handling or analysis. Rather, they anticipate that their interaction with data will remain action-oriented, responding to the information provided. It is projected that other roles within the organization will evolve to include the handling, analysis, and application of data that is used for decision-making.

"If you should recruit someone today or in ten years the most important thing is

still experience and knowledge within mechanics. You basically want a car mechanic from the 80s."

Due to the lack of change when Smart Maintenance is implemented, important competencies today will continue to be important in the future. The most important competencies found are analytical and communication skills. Analytical skills are key due to the wide possible problems blue-collar workers could face during maintenance tasks. Communication is important when transferring knowledge between shifts and employees especially if a gap in the communication structure exists.

Key Insights - Blue-collar in Smart Maintenance

- **Stable core responsibilities:** The core responsibilities of blue-collar workers, consisting of machinery repair and maintenance, are expected to continue with little variation in the future.
- **Importance of interpersonal skills:** In addition to functional skills, interpersonal skills like communication, teamwork, and personal drive are increasingly vital, especially in transferring knowledge and ensuring effective operations across shifts.
- **Future of Smart Maintenance:** With the rise of smart maintenance, understanding digital tools will become more crucial, although the primary interaction with data is expected to remain action-oriented rather than expanding into extensive data analysis.

4.1.3 White-collar in Smart Maintenance

The definition of white-collar workers at Northvolt in this report includes planners, supervisors, engineers and managers which are described in section 2.9.6. This grouping is done due to their similarities in necessary competencies to succeed.

The capabilities found for white-collar workers are the following:

- Data analytics competence
- Communication skill
- Teamwork
- Continuous learning
- Personal drive
- Calm mentality
- Maintenance understanding
- Language skills
- Presentation skills
- Troubleshooting skills
- Interdisciplinary thinking
- Prioritization skills
- Ability to listen
- Project management

- Planning capabilities
- Personnel management
- Mechanical competence
- Electrical competence
- Clean and dry room
- Chemical competence
- Digital tool understanding
- Asset management capability
- Process management
- Risk management capability
- Machine knowledge
- Safety procedures
- Work methods including documentation and reporting
- Teaching and training
- Preventative and predictive maintenance

As white-collar workers will be further away from the actual maintenance operations (maintenance work in the factory), capabilities focusing on practical work will be of less importance in comparison to management capabilities and data analytics skills. These skills will be utilized to a larger extent in the white-collar workers' daily operations and will therefore determine how well he or she perform. As white-collar workers are highly involved in transferring and transforming information from a strategy or management team higher up in the organization, communication capabilities, such as language skills and presentation skills, will be highly regarded. Combined with internal integration being a cornerstone of Smart Maintenance, the need for well-developed communication skills is complete. Despite this reasoning, it is important for the white-collar worker to fully understand the maintenance organization and the way Northvolt works with maintenance.

The current unsteady state, due to fast scaling, of Northvolt comes with circumstances that demand rapid troubleshooting, problem solving, and rapid decision taking, resulting in high demand for managerial capabilities for white-collar workers. Prioritizing tasks to achieve the needed short-term gain as well as long term success is essential. The first step to fruitfully prioritize is to realize all existing challenges, therefore the ability to listen is needed. Sequentially, project management, personnel management, and prioritization of task is necessary for the white-collar worker to successfully handle failure maintenance, while implementing Smart Maintenance and perform planned and preventative maintenance.

"Prioritization will be important for managers and supervisors. A lot of things is going on all the time and you cannot be everywhere at the same time"

According to interviews a larger shift towards data driven analytics will occur when implementing Smart Maintenance. As engineers and managers will have a larger focus on setting up and developing digital data processing tools, it is of the highest importance that these skills are current. Smart Maintenance is dependent on data

driven decision making and will therefore call for capabilities within this area. The transformation from analog and simpler analytical methods will most probably be a significant change for the demanded capabilities and skills.

"We use data today to measure downtime and look at specific processes but could put more focus on it to see what more can be achieved from it. Analyze and use data is a job for engineers as technicians already works with a lot of other tasks."

For white-collar workers' work methods, preventative and predictive maintenance will be increasingly important. These capabilities will be specifically tailored to the circumstances revolving around Northvolt's operations and will therefore be essential to complete a successful implementation of Smart Maintenance. Furthermore, understanding safety protocols and processes is of the highest priority when working in an industry setting containing mechanical, electrical, and chemical hazards, this knowledge will continue to be the most important when Smart Maintenance is implemented.

Key Insights - White-collar in Smart Maintenance

- **Focus on management and analytics:** For white-collar workers, practical maintenance skills are less critical compared to management capabilities and data analytics, which are essential for daily operations and overall performance.
- **Communication and information transfer:** Effective communication, including language and presentation skills, is crucial due to their role in transferring and transforming information from higher management, especially in the context of Smart Maintenance.
- **Importance of managerial capabilities:** Managerial skills such as project management, personnel management, and prioritization are vital for handling maintenance operations and implementing Smart Maintenance strategies.
- **Shift towards data-driven analytics:** With the shift to Smart Maintenance, there is an increased demand for skills in digital data processing and data-driven decision-making, highlighting the need for advanced analytics capabilities among engineers and managers.

4.2 Training

In this section results regarding training for technicians will be presented. Interviewees were asked about their thoughts on the training received at Northvolt and past employers (Appendix A). The results show a common understanding between interviewees for the necessity of training and the shortcomings of Northvolt's current training structure.

4.2.1 Current training structure

Training at Northvolt has evolved dynamically adapting to the organization's rapid expansion, employing various methods to equip new maintenance personnel with the necessary skills. Interviews with technicians, planners, engineers, and managers reveal a transition from an introductory phase consisting of practical, on-the-job learning to more structured training. Initially, training encompassed a mix of company orientation and hands-on experience alongside production operators, to evolve into a comprehensive, structured training program used today. The current state consists of a week-long introduction to Northvolt, presenting its key targets, values, safety routines, and specific knowledge needed to work at Northvolt, followed by an introduction at the Northvolt academy, an introductory maintenance education (IME), followed by specific maintenance training at the Northvolt academy where practical experience is gained and troubleshooting skills are trained. The program is finalized in the factory where you are working under the supervision of a more experienced maintenance technician.

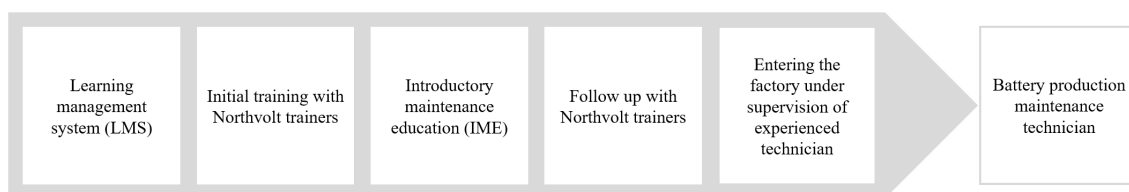


Figure 4.1: The current training path for battery maintenance technicians.

An overwhelming majority of the interviewed personnel stresses the importance of experience as a key for technicians working in the factory. Complexity is a common description of the tasks undertaken by the maintenance technicians on a daily basis, which by itself creates a demand for experience and a comprehensive understanding of the machines and the full production line. However, interviewees consistently pointed out that the current training lacks sufficient hands-on experience before entering the factory, a critical component for effective skill development in maintenance tasks. Combined with the common theme of lacking prior mechanical experience among new trainees, which complicates their learning curve, the challenge is growing even more as Northvolt continues to expand and recruit a large volume of employees.

"People coming from the introductory maintenance education have really limited knowledge."

The current training framework extends over several months, starting with a course through the Learning Management System (LMS). The course is designed to familiarize new personnel with Northvolt's most fundamental and practical knowledge. However, this segment's effectiveness is somewhat hampered by the volume of information dispensed in the condensed time frame, leading to information overload. Interviews have revealed that this phenomenon might require additional follow-up training, particularly in safety protocols to ensure that all employees have the fun-

damental competence needed to start working.

"The Charge Days are too intensive nobody can process that much information in just a couple of days."

Following is the introductory maintenance training (IME), mandatory for the majority of new maintenance technicians and serves as a platform for those unfamiliar with mechanical maintenance, building confidence in handling machinery by creating a fundamental base of knowledge on which more complex knowledge will be added. However, its utility for experienced personnel is questioned by a large share of the interviewed personnel, given its foundational nature. The IME training is complemented by in-house sessions focused on forming skills and mindsets relating to problem-solving and troubleshooting, incorporating hands-on experiences with specific factory equipment to bridge the gap between theoretical knowledge and practical application. Despite these efforts, feedback indicates that the practical experience is still insufficient to create competent maintenance technicians.

The subsequent phase involves new employees entering the factory and start working hands-on under the guidance of an experienced trainer. This critical stage heavily depends on the experienced employees' ability to teach knowledge and skills effectively. However, a notable issue is the absence of a standardized process for this knowledge transfer, leading to inconsistencies in the training quality received by new employees. This results in varied skill levels across different shifts, influenced significantly by the trainers' teaching methods. Expanding this challenge is a significant gap identified where the absence of detailed information about machine specifications from suppliers, makes it challenging to apply theoretical knowledge in practical settings. Due to the lack of standardized training structures and information about machines in combination with the unpredictable nature of maintenance work and high workloads, the trainers face challenges. This is making it difficult to provide consistent, quality training further enhancing the problem of teaching and learning hands-on experience in the running production.

"Today a lot is learning by doing and not structured training"

Lastly, interviewees highlighted several shortcomings in the LMS programs and courses. One significant issue is the absence of practical training due to the program's digital structure. Additionally, the ability to retake competence tests with the same questions allows for passing through repetitive attempts rather than true understanding. This approach not only poses a quality risk but, more importantly, a safety risk. To fully acquire a skill, employees need a combination of practical training and theoretical knowledge. Simply memorizing the answer patterns without understanding the underlying questions compromises the effectiveness and safety of the training.

"You can take them, LMS, basically a couple of times and at a certain point you will pass. It should not be possible to just try it a couple of times and only learn what's

the answer to each question without actually understanding it."

4.2.2 Suggestions to develop maintenance training

Reflecting on past training methods, several interviewees appreciated the previous approach that emphasized learning through shadowing production operators. This resulted in an extensive understanding for machines and the production process in general highlighting how practical experience can be gained working in production. Further, hiring from the production team was suggested, leveraging their firsthand knowledge of the machinery and operations. Training for operators in productions is also a quicker, more standardized process which could make the overall training process faster. Highlighted is also the possible gain in the relationship between the maintenance organization and the producing organization as more insight is gained into how the two sides operate. However, interviews indicate that hiring from operations would put a huge amount of stress on the production part of the organization which could lead to other unforeseen problems.

"When I started we worked with operators in the beginning to gain knowledge about the machines. I think this training was really good and gave me the necessary knowledge to solve some problems even more experienced technicians could not handle."

The idea of training camps was highlighted by several interviewees as a potential solution to the lack of practical experience before workers enter the factory. Training camps provide an intensive period of hands-on training in an environment that closely resembles actual working conditions. Consequently, there were proposals to use inactive production lines as training grounds, enabling new employees to acquire practical experience in a controlled setting

"I believe in camps, this is something currently in preparation for operators. Camps gives opportunities to gain hands-on experience, but the production lines currently used have high performance requirements which does not allow for extra downtime due to training. Therefore, the plan is to use lines currently in construction before they are ready to produce customer products."

Key Insights - Training

- **Recognized Training Needs:** Gaps in Northvolt's training programs are acknowledged, underlining the need for improved technician training.
- **Hands-On Experience Gap:** New technicians face a critical lack of practical experience, leaving them underprepared for real-world maintenance tasks.
- **Inconsistent Training Quality:** Training quality varies due to non-standardized procedures and dependence on individual trainers, resulting in uneven skill levels among new technicians.
- **Digital training problems:** LMS does not include practical training and

allows for repetitive competence tests, compromising training effectiveness and safety.

- **Improvement suggestions:**
 - **Practical Engagement:** Reintroducing previous training methods like shadowing production operators for their hands-on approach.
 - **Training camps:** Implementing training camps using inactive production lines for practical training in a controlled environment.

4.3 Work process

This subsection explores the similarities between the battery industry and other manufacturing sectors in terms of maintenance practices. Furthermore, it also highlights the current spread between planned and unplanned maintenance tasks at Northvolt Ett.

4.3.1 Similarities to other industries

Similar to earlier results regarding the lack of change for technicians when Smart Maintenance is implemented, the battery industry is not radically different from other producing industries. This was underscored by multiple interviewees as maintenance within production is the same independent of the industry itself and the battery industry follows this pattern. However, unique characteristics still exist such as the requirements of cleanliness, usage of dangerous chemicals, and high precision production. Cell Assembly is characterized as a highly clean and precise area, while the risk for chemical exposure are lower compared to other areas. These characteristics affect the work environment for involved employees. Interviews highlighted, that to achieve the right level of cleanliness specific training is required but the basic tasks of maintenance are still the same. Thus, results from the interviews show that mechanical knowledge and experience is what is important for fast development, and specific knowledge of each machine is developed through the job.

"Maintenance between industries is basically the same, machines break and maintenance repair them. The only difference is what machines are used and if it's high or low precision manufacturing."

Moreover, the interviews indicate a belief that these similarities with other production industries could and should be used by copying well established large-scale production companies. Several interviewees mentions SSAB, LKAB, and Volvo who have established methods on how to structure their maintenance organization. Learning from these are believed to be useful to establish a robust process that are able to cope with Northvolt's high production and scaling demands.

4.3.2 Planned and unplanned maintenance

Currently, the majority of maintenance tasks at Northvolt Ett are unplanned, primarily due to three factors: ongoing construction, high workload, and a shortage of skilled personnel. First, the factory is still under construction, and production lines have only recently begun to produce customer products. This phase often sees more frequent failures compared to more established factory settings. Second, the high workload on white collar maintenance personnel can be partly derived from taking on tasks typically performed by technicians. This impacts their ability to coordinate and carry out planned and preventive maintenance tasks with planners and engineers. Lastly, the lack of experienced personnel hinders technicians' ability to anticipate necessary maintenance before failures occur and affects white-collar workers' decisions on when to halt production for planned and predictive maintenance. Additionally, Northvolt's production targets necessitate continuous operation of production lines, which further limits opportunities for preventive and planned maintenance. Several interviewees noted that maintenance often becomes an afterthought in production settings, which can result in longer unplanned downtime than if preventive maintenance had been timely executed.

Key Insights - Work process

- **Industry Similarities:** The maintenance processes in the battery industry are largely similar to other production industries, with some distinct characteristics like the need for high cleanliness, handling of dangerous chemicals, and precision in production.
- **Learning from Leaders:** The possibility of adopting best practices from established large-scale production companies like SSAB, LKAB, and Volvo is seen as beneficial for structuring a robust maintenance process at Northvolt.
- **Unplanned Maintenance Predominance:** A significant portion of maintenance tasks at Northvolt Ett are unplanned, influenced by ongoing construction, high workloads, and a shortage of skilled personnel.
- **Maintenance Prioritization Issues:** Maintenance is often deprioritized, resulting in longer unplanned downtimes than if preventive maintenance had been timely executed.

4.4 Capability mapping and its complexity

Findings from interviews and observations revealed challenges in using capability matrices for mapping maintenance capabilities. Participants pointed out that the work involved in both performing and maintaining these matrices is complex, primarily because the nature of maintenance tasks differs significantly from the fundamentals of production. Capability mapping is often used within production to evaluate employees' competencies and therefore develop to suit this specific environment.

It was noted that maintenance tasks incorporate a high degree of complexity due to their unpredictable nature and the variability of issues that can arise with different machinery. This complexity makes it challenging to use capability matrices effectively as they often cannot accommodate the broad range of potential maintenance scenarios. Further insights indicated that unlike operational roles in production where tasks are performed within a well-defined and finite set of procedures, maintenance work can be executed in numerous ways. This variability complicates the standardization of maintenance tasks, making it more difficult to define and maintain consistency in capability matrices. Operators have an easier time using these complex and well-defined capability matrices because their job functions are more straightforward and can be captured within finite operational boundaries.

Additionally, it was found that comprehensive work instructions for all possible maintenance scenarios are impractical and close to impossible to create due to the vast number of possible tasks and faults. This limitation further enhances the difficulties in using capability matrices effectively, as they cannot fully encapsulate the detailed nuances of every potential maintenance task. The importance of having detailed machinery documentation was emphasized, which helps maintenance technicians, even those with no more than baseline skills, to perform most tasks efficiently by referring to guidelines in machinery documentation, such as acceptable performance intervals for specific machinery components.

"The effectiveness of work instructions is heavily compromised if instructions of the machines is missing. You need to have these to understand how the machine is supposed to work or what intervals certain processes must be within."

The interviews also revealed that when maintenance work cannot be performed by a certain technician or shift, there needs to be an efficient and correct process for escalating these tasks. This ensures that they are quickly redirected to the appropriate personnel who are better equipped to handle them according to the matrices.

Overall, the findings underscored the complexities involved in using capability matrices for maintenance tasks at Northvolt, with their effectiveness often hindered by the intricate and variable nature of maintenance work compared to more predictable and standardized operational tasks.

Suggested to counteract the difficulty of creating functioning work instructions for each problem and work encountered sufficient documentation of how tasks have been handled is needed. Reporting and documentation of maintenance jobs done will create a blueprint or at least guidelines for how a job can be done in the future. However, this would require proper reporting guidelines to create standardization of how reporting is done, partly to create quality and to ensure that the documentation can be used effectively. Interviews also suggest that proper IT systems are needed to succeed in creating a working reporting and documentation culture. The situation today is presented to be insufficient in facilitating this reporting structure as the

systems do not support this function in a way that is easy enough to use. Lacking today is also a structure for naming reports and documentation so that they easily can be found when needed.

Key Insights - Capability mapping and its complexity

- **Complexity of Maintenance Tasks:** Maintenance tasks' unpredictable and variable nature makes capability matrices less effective due to their inability to cover all scenarios.
- **Documentation Limitations:** Comprehensive work instructions are impractical. Instead, detailed machinery documentation is vital for guiding technicians efficiently.
- **Escalation Processes:** Proper escalation processes are needed to manage tasks that exceed the capabilities of certain technicians, ensuring efficient task handling.
- **Reporting and Documentation Needs:** Adequate support systems and standardized reporting guidelines are crucial to improve maintenance documentation and its accessibility for future use.

5

Creation

The three research questions formulated in section 1.6 will be answered in this section. The first research question will be answered in section 5.1, the second will be answered in section 5.2, and the last question will be answered in 5.3.

5.1 Capabilities in battery maintenance

The first research question is stated as "What capabilities are needed for battery production maintenance technicians, team-leaders, supervisors, planners, engineers, and managers to successfully implement Smart Maintenance?". To answer this, capabilities will be mapped in this section to formulate what is needed in terms of capabilities for Smart Maintenance in battery manufacturing.

5.1.1 Mapped capabilities

Capabilities highlighted by interviews and literature will now be discussed and compared. Some capabilities overlap, while some capabilities are highlighted by one of the two forums. The reason for some capabilities only being found in the empirical study at Northvolt can be explained by the following. First, battery manufacturing will have some competencies that are unique to its industry. Maintenance in the battery industry will, to some degree, not be identical to maintenance in other industries due to different machinery, work processes, demand from production, and quality requirements. Second, some capabilities will be unique to Northvolt due to work structures, safety routines, and other Northvolt-specific structures and work processes. Therefore, the three types, general, industry-specific, and firm-specific will be used to divide the found capabilities, this division is further described in 2.7.2. This division of capabilities will be the foundation on which the training structure will be based. Generating general capabilities can be outsourced to other organizations, while Northvolt will have to ensure that industry-specific and firm-specific capabilities are created by themselves.

Below in table 5.1 are all found capabilities summarized and categorized into general, industry-specific, and firms-specific. In the coming parts, each capability will be described and motivated as to why they fit into the designated category.

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General capabilities	Industry-specific capabilities	Firm-specific capabilities
Ability to listen Adaptable and flexible Analyzing skills Asset management capability Calm mentality Communication skills Critical thinking Data analytics skills Decision making Delegation Digital tool understanding Electrical competence Escalation Interdisciplinary thinking Language skills Maintenance understanding Mechanical competence Personal drive Personnel Management Planning Presentation skills Preventative and predictive maintenance Prioritization skills Process Management Process Understanding Project Management Reporting and documentation Risk management capability Self-learning Teaching and training Teamwork Time Management Troubleshooting skills Work Methods	Chemical competence Clean and dry rooms Machinery knowledge	Product knowledge Safety routines Work method and ethics

Table 5.1: Capabilities categorized.

5.1.1.1 General Capabilities

Following is a presentation of the found capabilities that are relevant for the maintenance organization. The list is based on empirical and literature findings. The capabilities are divided into general, industry-specific, and firm-specific capabilities to create the foundation on which further discussions will be formed.

1. **Analyzing skills:** The employee will show greater analytical capabilities to examine breakdowns and their cause (Benhamza Hlihel et al., 2024). Interviews highlight a need to understand how actions taken at a specific place in the production affect other parts, both upwards and downwards from the machine being worked on. As specific instructions and fault code indexation are sometimes missing at Northvolt, the call for this skill is strengthened.

This is a skill demanded in maintenance organizations in numerous industries highlighted by its existence in the Swedish Standards Institute (SIS) and the European Skills, Competencies, Qualification, and Occupations Organizations (ESCO) competency database. (Institute, 2014; European Skills/Competences, Qualifications and Occupations (ESCO), 2024; Benhamza Hlihel et al., 2024).

2. **Data analytics skills:** As implementation of data-driven decision-making tools are introduced, the need for data analytical skills is needed (Bengtsson and Berglund, 2024; Benhamza Hlihel et al., 2024). Finding correlations, and setting up algorithms to automate predictive maintenance calls for data analytical and correlation skills were all mentioned by interviewees.

Data analytical skills are described by SIS as demanded by general maintenance staff, as well as by other literature (Institute, 2014; Benhamza Hlihel et al., 2024).

3. **Communication skill:** Communication has room for improvements at Northvolt and was highlighted by the interviews. Smart Maintenance is inherently dependent on internal integration (Bokrantz et al., 2020a). To have well-developed skills in communication is, therefore, crucial to succeed in creating integration within the company (Benhamza Hlihel et al., 2024).

Effective communication skills are essential across various maintenance roles, particularly for conveying complex information clearly and efficiently within the organization, as supported by industry literature (Institute, 2014; Benhamza Hlihel et al., 2024; Akyazi et al., 2022).

4. **Teamwork:** Maintenance is a team effort consisting of various parts, roles, and teams. To create a well-functioning organization that works with the tasks in hand, teamwork will be crucial (Benhamza Hlihel et al., 2024). Interviews highlight the need for combining capabilities from various parts of the maintenance organization to succeed in Smart Maintenance. Therefore, Northvolt

has to make sure that silo thinking does not occur, which calls for teamwork capabilities.

The requirement for teamwork in maintenance settings is well-documented, emphasizing the need for collaborative skills among maintenance personnel as a general capability (Akyazi et al., 2022; Benhamza Hlihel et al., 2024).

5. **Maintenance understanding:** Several interviews highlight the importance of a general understating of maintenance and its processes regardless of the position within the maintenance organization. For blue-collar being at the core of the operation, maintenance understanding is crucial. Furthermore, white-collar employees equally need to have a good understanding of the maintenance methodology and work structure to be able to plan, write work instructions, and lead maintenance teams efficiently.

A comprehensive understanding of maintenance methodologies is crucial for effective maintenance management, widely acknowledged in the literature as a fundamental skill for maintenance professionals (Akyazi et al., 2022; Benhamza Hlihel et al., 2024).

6. **Troubleshooting skills:** Finding the cause for a failure in the production calls for troubleshooting skills (Hernandez-de Menendez et al., 2020; Bengtsson and Berglund, 2024). To find and solve the root cause the maintenance staff must be able to effectively troubleshoot and problem-solve to minimize downtime in the production. This skill was mentioned in several interviews and seen as one of the most important to succeed as a blue-collar worker within the maintenance organization.

Troubleshooting is a key competency required in maintenance, extensively recognized in the literature as a critical skill for identifying and resolving issues efficiently (Akyazi et al., 2022; Benhamza Hlihel et al., 2024; Institute, 2014).

7. **Interdisciplinary thinking:** Interviews highlight a call for interdisciplinary thinking. The need to understand the full organization is emphasized as crucial for making correct and safe decisions when performing maintenance tasks.

Interdisciplinary thinking in maintenance is crucial for integrating various knowledge areas, a capability that is increasingly recognized in the maintenance literature as essential for modern maintenance practices (Jooste et al., 2020; Kipper et al., 2021).

8. **Critical thinking:** Maintenance staff will have to make in-the-moment decisions, evaluate safety risks, and find suitable solutions to problems (Benhamza Hlihel et al., 2024; Kipper et al., 2021). Smart Maintenance will provide the opportunity to analyze a large amount of data in real-time, resulting in the maintenance staff having the opportunity to evaluate a situation through

many different data points (Mobley, 2002).

Critical thinking is widely regarded in the literature as a necessary skill for maintenance personnel, enabling them to make informed decisions quickly and effectively (Benhamza Hlihel et al., 2024; Akyazi et al., 2022).

9. **Language skills:** To successfully communicate within maintenance teams and between divisions within Northvolt, maintenance personnel must have well-developed language skills (Hernandez-de Menendez et al., 2020). As several maintenance tasks are related to high risks if wrong calls are made, language skills are crucial for a safe maintenance organization. Further, interviews describe white-collar employees as a filter between upper management to blue-collar workers and therefore have to be able to communicate information in an effective and qualitative way, which further enhances the need for sufficient language skills from both messenger and receiver.

The significance of language skills in maintenance is broadly supported in the literature, indicating that effective communication across different levels of an organization is vital for the safety and efficiency of maintenance operations (Benhamza Hlihel et al., 2024; Hernandez-de Menendez et al., 2020; Akyazi et al., 2022; Institute, 2014).

10. **Presentation skills:** To describe visions, targets, and strategy a certain level of presentation skills is needed. This skill will be more relevant for employees communicating strategy from upper management downwards.

Presentation skills are essential in the maintenance field, especially for those in leadership roles who must clearly communicate strategic directions and safety procedures, a general capability highlighted across maintenance literature (Benhamza Hlihel et al., 2024; Institute, 2014).

11. **Prioritization skills:** For a scaling organization like Northvolt, prioritization will have to be made as there are more problems to solve than resources to work with (Zahiraldinni, 2022). Interviews showcase how much potential for development exists, however, time is limited, and prioritization between challenges and developments has to be made.

The ability to prioritize effectively is widely recognized in maintenance literature as crucial for managing resources efficiently and ensuring that critical maintenance tasks are addressed promptly (Zahiraldinni, 2022).

12. **Ability to listen:** Maintenance staff should be good listeners to be able to receive information regarding maintenance tasks. White-collar employees additionally have to accept the feedback received from the rest of the maintenance organization to optimize the work structure used in maintenance.

Listening skills are often underscored in maintenance literature as crucial for understanding and effectively responding to feedback and instructions within the maintenance environment (Akyazi et al., 2022).

13. **Decision making:** Maintenance is often a time-sensitive measure and therefore calls for efficient decision making (Hernandez-de Menendez et al., 2020). Downtime should be minimized while critical issues arise. The result is highly stressful situations where decisions relating to problem-solving and repairs need to be made (Bengtsson and Berglund, 2024).

Decision-making skills are highlighted as a general capability in maintenance literature, emphasizing the importance of making quick and accurate decisions in high-pressure situations to minimize downtime and ensure safety (Institute, 2014; Benhamza Hlihel et al., 2024; Hernandez-de Menendez et al., 2020; Bengtsson and Berglund, 2024).

14. **Self-learning:** Maintenance staff needs to consciously improve their capabilities, partly to become a better maintenance employee, and partly due to ever-evolving technologies and circumstances surrounding the maintenance organization (Hernandez-de Menendez et al., 2020). Smart Maintenance will put even more stress on learning as more technologies will be implemented into the daily maintenance operation (Emmanouilidis et al., 2011).

The need for self-learning is widely recognized in maintenance literature, particularly in the context of Industry 4.0, where continuous learning and adaptation to new technologies are essential (Benhamza Hlihel et al., 2024; Hernandez-de Menendez et al., 2020; Akyazi et al., 2022).

15. **Calm mentality:** Interviews indicate that keeping a calm mentality is crucial within the maintenance organization. Stressful situations occur regularly, leading to the need to stay calm and focused to solve problems efficiently.

Maintaining a calm demeanor is generally regarded as crucial in maintenance literature, especially in high-stress environments where clear thinking and effective problem-solving are required (Benhamza Hlihel et al., 2024; Hernandez-de Menendez et al., 2020).

16. **Personal drive:** As machines can fail in various ways, there are no standard processes to solve all potential problems that may occur. Maintenance staff will therefore need to take more responsibilities by themselves to find solutions. Personal drive to find solutions and to take responsibility for their own work will therefore be crucial for maintenance personnel (Hernandez-de Menendez et al., 2020).

Personal drive is a general capability highlighted in the maintenance literature, particularly in terms of taking initiative and being proactive in addressing and

solving maintenance issues (Hernandez-de Menendez et al., 2020).

17. **Adaptable and flexible:** Similarly to personal drive, personnel in the maintenance organization need to be able to adapt to new situations, technical tools, and work structures (Jerman et al., 2020; Hernandez-de Menendez et al., 2020). Smart Maintenance will enhance complexity within systems and create rapid change when implemented, further calling for adaptability and flexibility.

The ability to be adaptable and flexible is extensively recognized in the maintenance literature as critical for coping with the dynamic nature of modern maintenance environments and technological advancements (Benhamza Hlihel et al., 2024; Akyazi et al., 2022).

18. **Mechanical competence:** Interviews clearly state that specific mechanical skills are needed for maintenance within the battery industry. The battery production process consists of numerous machines with moving, mechanical parts needing maintenance on a regular basis (Rahimzei et al., 2018). Examples of mechanical skills highlighted in interviews are pneumatic skills, welding skills, and measurements of bearings.

Mechanical skills are fundamentally essential for maintenance personnel, especially in industries like battery production where precise mechanical knowledge is crucial for the operation and maintenance of complex machinery (Rahimzei et al., 2018; Zahiraldinni, 2022; Bengtsson and Berglund, 2024; Akyazi et al., 2022; Benhamza Hlihel et al., 2024; Institute, 2014).

19. **Electrical competence:** Electrical knowledge is also needed in a maintenance organization. Interviews state that more and more electrical components are integrated into the production leading to a larger demand for electrical knowledge (Rahimzei et al., 2018). Example of electrical skills highlighted in interviews are high voltage skills, electrical components, and wiring.

The need for electrical skills in maintenance is well-documented in the literature, especially as industries increasingly integrate more sophisticated electrical systems into their production processes (Rahimzei et al., 2018; Zahiraldinni, 2022; Bengtsson and Berglund, 2024; Akyazi et al., 2022; Benhamza Hlihel et al., 2024; Institute, 2014).

20. **Digital tool understanding:** More maintenance is relying on digital tools when troubleshooting and while working on a machine (Ayerbe et al., 2021). Employees within the maintenance organization need to have knowledge about these digital tools, both on how to operate them and how they work to be able to perform maintenance on them.

The understanding of digital tools is increasingly vital in maintenance, as highlighted in the literature, reflecting the growing integration of digital tech-

nologies in modern maintenance practices (Jooste et al., 2020; Kipper et al., 2021; Benhamza Hlihel et al., 2024; Akyazi et al., 2022).

21. **Asset management capability:** Asset management will be crucial for battery maintenance as prioritization between different maintenance tasks. The foundation of successful prioritization will be to determine the criticality of assets. The ability to define and prioritize assets to formulate criticality of assets will therefore be crucial for the maintenance organization. The same principle can be used when managing the stock of spare parts to make sure that vital parts for the production function (Swanson, 2001).

Asset management skills are broadly recognized in maintenance literature as essential for effectively managing resources, scheduling maintenance activities, and ensuring optimal production efficiency (Benhamza Hlihel et al., 2024; Institute, 2014; Jooste et al., 2020).

22. **Risk management capability:** Similar to asset management, risk management will play a crucial role in the maintenance organization. Defining risks of failure and risks of maintenance work will be crucial to be able to prevent accidents from happening and limit the outcome of failures (Akyazi et al., 2022).

Risk management capabilities are extensively documented as a general skill in maintenance literature, critical for anticipating potential failures and implementing preventive measures to mitigate risks (Akyazi et al., 2022; Institute, 2014; Jooste et al., 2020).

23. **Reporting and documentation:** As maintenance in the battery industry is a relatively new phenomenon, many best practices are yet to be formed. To successfully form best practices, reporting and documentation of faults and solutions are crucial (Akyazi et al., 2022). To pass information to other shifts, employees, or parts of the organization, reporting and documentation have to be in place. Interviews have highlighted this as essential to quickly build experience within the organization.

Reporting and documentation skills are emphasized as fundamental in the maintenance literature for effectively communicating and maintaining records of maintenance activities, which is crucial for continuous improvement and knowledge transfer (Akyazi et al., 2022; Institute, 2014; Benhamza Hlihel et al., 2024).

24. **Teaching and training:** The battery industry has to ensure that gained knowledge does not get lost due to poor handover trainer capabilities (Hernandez de Menendez et al., 2020). Transferring competences, skills, or knowledge is therefore of the highest importance.

Teaching and training skills are crucial in the maintenance sector, especially in industries undergoing rapid technological changes where continuous employee development and knowledge transfer are essential (Jooste et al., 2020; Institute, 2014; Benhamza Hliheli et al., 2024; Akyazi et al., 2022).

25. **Preventative and predictive maintenance:** Smart Maintenance will enable effective use of both preventative and predictive maintenance (Bokrantz et al., 2020b). To fully utilize Smart Maintenance in battery manufacturing, both these concepts will have to be used. The opportunity to make use of both predictive and preventative maintenance comes from the use of data and analytical tools that can indicate when maintenance needs to be scheduled (Liu et al., 2019).

Preventative and predictive maintenance skills are heavily emphasized in the literature as vital for modern maintenance practices, allowing organizations to optimize maintenance schedules and reduce unexpected downtime (Akyazi et al., 2022; Institute, 2014).

26. **Time Management:** In a maintenance organization, time management involves efficiently scheduling and executing maintenance tasks to minimize downtime for machinery and production lines (Benhamza Hliheli et al., 2024; Institute, 2014). This capability ensures that preventive and corrective maintenance is performed within operational windows to maximize productivity and equipment longevity.

Time management is mentioned in literature as an important capability, primarily for positions with responsibility over personnel (Benhamza Hliheli et al., 2024; Institute, 2014). Therefore, this capability should be seen as a general capability.

27. **Delegation:** Delegation within a maintenance team entails assigning the right maintenance tasks to the right team members based on their skills, experience, and current workload (Benhamza Hliheli et al., 2024). Effective delegation helps in optimizing resource utilization, fostering team learning, and ensuring that maintenance activities are completed efficiently and effectively.

As this skill is recognized in the literature as important for managers and supervisors in maintenance organizations, this should be seen as a general capability (Benhamza Hliheli et al., 2024).

28. **Escalation:** Escalation is a critical capability in maintenance organization broadly highlighted by interviews, referring to the ability to understand when to elevate issues beyond usual management lines if normal procedures fail. This ensures that significant maintenance issues are addressed swiftly and by the appropriate level of authority to prevent extended downtime or damage.

Escalation is also mentioned in literature by Benhamza Hlihel et al. (2024) as important in modern maintenance organizations, resulting in this skill being general.

29. **Process Understanding:** Process understanding in maintenance involves comprehending the operational workflows, machine functions, and systems within the facility (Benhamza Hlihel et al., 2024). This knowledge is essential for diagnosing problems accurately, performing effective maintenance, and optimizing the machinery's performance and safety.

Effective process understanding allows maintenance personnel to effectively engage with complex manufacturing environments and apply targeted maintenance strategies, which is crucial in educational settings such as learning factories (Jooste et al., 2020; Akyazi et al., 2022). The skill being mentioned extensively in the literature indicates this being a general capability.

30. **Process Management:** Process management in maintenance involves overseeing and improving the processes used for maintaining equipment and facilities (Akyazi et al., 2022). This is an evolved competence from process understanding which is required to manage processes. It includes the development of maintenance strategies, the standardization of procedures, and the implementation of best practices to enhance operational efficiency and reliability (Institute, 2014).

31. **Project Management:** Project management in a maintenance organization entails planning, executing, and finalizing projects according to strict deadlines and within budget. This includes acquiring resources, coordinating team members, and integrating and performing maintenance activities that improve operational support and renewal projects.
As this concept is broadly recognized as an important competence for managers this is a general competence (Akyazi et al., 2022; Institute, 2014).

32. **Planning:** Planning in maintenance management is the process of scheduling, resource allocation, and logistics planning to ensure that maintenance activities are forecasted, well-organized, and executed without interrupting production unnecessarily (Akyazi et al., 2022). Effective planning helps in optimizing maintenance interventions, reducing costs, and extending the life cycle of equipment.

This concept is recognized in literature to be important in maintenance organizations, not the least for planners. Therefore, this is a general capability (Akyazi et al., 2022; Institute, 2014).

33. **Personnel Management:** Personnel management in a maintenance setting involves managing the human resources aspect of the maintenance team. It includes tasks such as hiring, training, and developing staff, as well as manag-

ing their performance, and ensuring they have the necessary tools and training to perform efficiently and safely.

Personal management is mentioned as important for maintenance managers and supervisors by Institute (2014) as well as Akyazi et al. (2022). Therefore, personnel management is a general capability that can be expected to be found outside of the battery industry,

5.1.1.2 Industry specific capabilities

Some of the capabilities that were mentioned by Northvolt cannot, to a significant extent, be found in the literature review performed unless being in literature relating to battery production. These capabilities are industry-specific and include:

1. **Chemical competence:** As battery production relies on chemicals that are both dangerous and hazardous if not handled with care, a general chemical knowledge about the chemicals in battery production is needed (Rahimzei et al., 2018). Cell Assembly does directly handle active chemicals like electrolytes, leading to the importance for all people moving in the battery production facility to know how to handle specific chemicals in case of an emergency (Aydin et al., 2023).

Chemical skills are emphasized as essential in the literature, particularly in industries involving hazardous materials, underscoring the need for proper handling and safety procedures to prevent accidents and ensure safety (Rahimzei et al., 2018; Aydin et al., 2023).

The requirement for chemical skills in the battery industry is particularly pronounced due to the volatile and reactive nature of the materials involved in battery manufacturing. The potential risks associated with chemical handling in battery production necessitate a higher level of vigilance and specialized knowledge. This distinct emphasis on chemical competencies is uniquely tailored to the battery industry's operational environment, where even minor chemical mismanagement can lead to significant safety incidents and operational disruptions. Therefore, the chemical skills needed for battery manufacturing and the maintenance of it can be seen as unique for the industry (Rahimzei et al., 2018).

2. **Machinery knowledge:** To have the possibility to do maintenance work effectively, maintenance staff needs to have sufficient knowledge of the machines being in production at Northvolt.

The need for in-depth machinery knowledge at Northvolt is critically emphasized by the sophisticated and advanced nature of the production equipment used in battery manufacturing (Aydin et al., 2023). The machines used in this sector are often at the cutting edge of technology, incorporating complex sys-

tems that require precise understanding and handling (Rahimzei et al., 2018). This specialized knowledge is essential not only for routine maintenance but also for troubleshooting and optimizing machine performance, which directly impacts the overall efficiency and productivity of the manufacturing process. The unique characteristics of battery production machinery, including their precision, sensitivity to environmental conditions, and integration with digital technologies, make this capability specific to the industry.

- 3. Clean and dry rooms:** As a substantial part of the production occurs in clean and dry environments, maintenance personnel operating in these environments need to have knowledge on how to behave, both in terms of entering and in terms of operating to not create contamination (Rahimzei et al., 2018; Aydin et al., 2023). As working on machines can create contamination in terms of dust and smaller particles, and bringing spare parts into these environments can bring in contaminating particles, it is crucial to have the correct skills and capabilities to operate in these environments.

The implementation of clean and dry rooms in the battery manufacturing process is a distinctive feature that underscores the specialized requirements of this industry. Unlike many other manufacturing sectors, the battery production environment demands exceptionally low levels of contaminants and moisture (Rahimzei et al., 2018). This is crucial because even minute particles or variations in humidity can significantly impact the quality and performance of batteries (Aydin et al., 2023). Such conditions are specifically tailored to meet the unique chemical sensitivity and precision needed for battery components, ensuring the integrity and functionality of the final product. Therefore, the utilization of clean and dry rooms is not just a standard procedure but a critical necessity unique to the battery industry due to its specific production characteristics.

5.1.1.3 Firm-specific capabilities

Other capabilities that have been mentioned in interviews are specific to the Northvolt organization and cannot be found in the literature. These include the following:

- 1. Safety routines:** Knowing safety routines and procedures is crucial for a maintenance employee. Due to a variety of work, maintenance technicians will have to know many different safety routines specific to different machines and chemicals. Due to each organization's unique structure are these skills firm-specific, each employee needs to understand the safety routines used at Northvolt.
- 2. Work method and ethics:** Several interviews highlight that differences between maintenance in battery manufacturing compared to other producing industries are slim. However, it is highlighted that working at Northvolt differs significantly from other companies due to the unique situation of the company. To realize these differences in work methods and work ethics will be crucial

to ensure efficient workflows and frictionless collaborations between coworkers and in between teams. This could for example be the attitude toward innovation, how to handle cultural differences in this multi-cultural company, and routines of handling tools are being carried out.

3. **Product knowledge:** Interviews underlined the need for understanding the product for maintenance personnel. Northvolt produces different kinds of batteries resulting in the occasional need to edit the settings of machinery. Maintenance personnel at Northvolt needs to be able to perform these actions and is therefore entailed to have this knowledge.

5.1.2 Applying capabilities to different roles

All above-mentioned capabilities will not be essential for each and every position within the maintenance organization. Some will be more important for blue-collar workers and others will be more important for white-collar workers. In the report, there will be a discussion and reasoning around which capabilities are more important for which roles.

However, as highlighted by the interviews and presented in the result, dividing capabilities into complex matrices might be counterproductive. Complexity could make the capability matrix less valuable than it could be and therefore not used. Therefore, presented in this report is a simplified solution where a baseline for maintenance staff will be created. This baseline is a competency level of which is needed for a maintenance employee to work independently and consequently is the capability level that should have been achieved when leaving training to work as a maintenance employee. However, different staff will need different capabilities, and therefore will different baselines be created for both blue-collar and white-collar workers.

5.1.2.1 Blue-collar capabilities

The capabilities found to be essential to start working in the factory can be seen in table 5.2. These capabilities are valid for blue-collar workers, essentially meaning maintenance technicians. In the table below are the baseline capabilities presented and later discussed.

General capabilities	Industry-specific capabilities	Firm-specific capabilities
Adaptable and flexible Calm mentality Communication skills Digital tool understanding Documentation and reporting Electrical competence	Chemical skills Clean and dry rooms Machinery knowledge	Northvolt-Safety Northvolt work ethics

Escalation		
Language skills		
Maintenance understanding		
Mechanical competence		
Personal Drive		
Self-learning		
Teamwork		
Time management		
Troubleshooting		

Table 5.2: Categorized capabilities for blue-collar workers in battery maintenance.

As blue-collar workers primarily are technicians the capabilities needed will be focused on performing manual labor. SIS confirms the need for mechanical and electrical capabilities stated in interviews (Institute, 2014). Further, documentation and communication skills, including language skills, are mentioned to be important to succeed as a maintenance technician, not the least in a multi-cultural organization such as Northvolt. The literature further confirms the interviews that skills as teamwork, decision making, continuous/self-learning, and digital tool understanding are important capabilities for maintenance technicians (Benhamza Hlihel et al., 2024). For maintenance technicians capabilities that relate to the general work process of maintenance are essential to understand. Therefore is maintenance understanding and troubleshooting important capabilities as well (Benhamza Hlihel et al., 2024).

Interestingly, the skills called open-mindedness and personal drive are more difficult to find in the literature. However, the empirical findings show a clear demand for these capabilities at Northvolt. This could possibly be explained by the state in which Northvolt exists, expanding rapidly from nothing to a functioning battery manufacturer. As the European battery industry is in its cradle it is highly likely that these skills will stay relevant over the foreseeable future in Europe.

Smart Maintenance will affect blue-collar employees when implemented, however, it will not substantially impact the daily work of blue-collar employees. Smart Maintenance will impact maintenance organizations, how maintenance is planned, and how resources are divided within the organization (Bokrantz et al., 2020a,b,c). Moreover, the empirical study in this report shows that data-driven decision making including digital tools will not substantially alter the way technicians perform maintenance. The maintenance works will still have to be carried out by maintenance personnel who are dependent on mechanical and electrical skills to perform the job. However, Smart Maintenance could create a better work climate as fewer jobs are acute maintenance work, and more is planned maintenance. Interview highlights that some of today’s maintenance jobs are of acute characteristics, and Smart Maintenance could therefore be used to level out the uneven workload.

The battery industry demands specific capabilities that are needed for all employees

working in battery production. As Cell Assembly is within a clean and dry room, these skills are crucial to understand (Rahimzei et al., 2018). Similarly, specific Northvolt safety routines and chemical knowledge are essential to ensure a safe work environment for the employees. Furthermore, knowledge regarding the specific machinery at Northvolt will be necessary to actually be able to perform maintenance jobs.

5.1.2.2 White-collar capabilities

White-collar workers include managers, supervisors, planners, and engineers. Despite largely demanding similar capabilities, the different positions have some differing characteristics demanding a division of this group. Managers and supervisors both have responsibility over personnel and will therefore be discussed together, while planners and engineers will demand similar capabilities and therefore be handled together. In the two tables below, the baseline capabilities found for both groups are presented and later discussed.

In table 5.3 the capabilities for managers and supervisors are shown, and in table 5.4 the capabilities for planners and engineers are shown.

General capabilities	Industry-specific capabilities	Firm-specific capabilities
Ability to listen	Chemical competence	Northvolt safety
Asset management capability	Clean and dry rooms	Product knowledge
Calm mentality	Machine knowledge	Work method
Communication skills		
Data analytical skills		
Decision making		
Delegation		
Digital tool understanding		
Documentation and reporting		
Electrical competence		
Interdisciplinary thinking		
Language skills		
Mechanical competence		
Personal Drive		
Presentation skills		
Preventive and predictive maintenance		
Prioritization skills		
Process management		

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Risk management capability Self-learning Teamwork Training and teaching Troubleshooting skills		
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Table 5.3: Categorized capabilities for managers and supervisors in battery maintenance.

General capabilities	Industry-specific capabilities	Firm-specific capabilities
Ability to listen Analyzing skills Asset management capability Calm mentality Communication skills Data analytical skills Decision making Delegation Digital tool understanding Documentation and reporting Electrical competence Interdisciplinary thinking Language skills Mechanical competence Personal Drive Planning Presentation skills Predictive and preventative maintenance Prioritization skills Process management Process understanding Project management Risk management capability Self-learning Teaching and training Teamwork	Chemical competence Clean and dry rooms Machine knowledge	Northvolt safety Product knowledge Work method

Troubleshooting skills		
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Table 5.4: Categorized capabilities for planners and engineers in battery maintenance.

The interviews highlight the importance of understanding the basic maintenance knowledge that is important for blue-collar personnel. It is stressed that to plan, write work instructions, or manage maintenance teams, white-collar workers must have a deep understanding of the daily operation. This is strengthened by the fact that Northvolt moves personnel from blue-collar positions to white-collar positions where potential is seen. Various studies confirm this view by mostly leveling up criteria for white-collar workers compared to blue-collar workers, as well as adding capabilities (Benhamza Hlihel et al., 2024; Institute, 2014). The ALBATTS project carried out by the European Union highlights different levels of knowledge that are needed for maintenance technicians and for maintenance engineers and the biggest differences between the two can be seen in the levels of expertise in combination with some added capabilities for the engineers (Project ALBATTS, 2023b,c).

Managers and supervisors will additionally have to deal with managing maintenance employees. It is therefore important to have the skills to lead people and to communicate information and strategies to the maintenance teams. Presentation skills will therefore be an important capability for these roles to inherit (Benhamza Hlihel et al., 2024). Additionally, all white-collar positions will face challenges when implementing Smart Maintenance. New technologies and digital tools will have to be taught and learned (Bokrantz et al., 2020a; Benhamza Hlihel et al., 2024). Similarly, will preventative and predictive maintenance play a decisive role when Smart Maintenance is implemented. The data-driven decision-making processes that come with Smart Maintenance will have to be handled by white-collar employees. Planners are today handling planned maintenance in combination with downtime. It is therefore crucial that planners learn how to incorporate and use data to better plan maintenance. Further, engineers could ensure better work instructions and maintenance instructions to make the maintenance work easier by connecting them to fault codes and warnings. Managers can use data-driven planning systems to continuously ensure the right competence in each shift work and by this ensuring that a vast majority of all problems occurring during the shift can be solved.

5.2 Training for maintenance in battery manufacturing

The second research question is stated as "How should an overarching training structure be developed to ensure a qualitative battery production maintenance technician workforce?". This is answered by creating a training structure for maintenance technicians where the training will be tailored depending on what experience the employee previously has.

5.2.1 Structuring training

Training is essential for both new and current workforce to be able to perform their expected work. This is also essential for the company to attain a competitive advantage compared to its competitors. As mentioned by Elnaga and Imran (2013) employees who are not able to perform their expected tasks to a satisfactory level are more likely to leave the company. Improved training programs could therefore decrease employee turnover.

The findings from the literature show training including multiple ways of teaching increases both learning and motivation (Uslu et al., 2021; Ibrahim et al., 2017). These results are backed up by empirical data where interviewees highlight the importance of not only theoretical knowledge but also practical training to acquire the skill. Furthermore, Ibrahim et al. (2017) concluded that spaced repetition with the opportunity to internalize the training increases knowledge gains. Therefore, training should include a multifaceted teaching structure where workers are able to rehearse the knowledge in different ways to later turn it into actual skills through practical training.

Furthermore, both interviews and literature express favorable views for on-site training compared to web-based formats (Lacerenza et al., 2017). One significant advantage noted is the ability to certify the quality of training, as trainers or instructors can directly validate employees' learning. Lacerenza et al. (2017) also highlights that on-site training provides superior opportunities for feedback. According to Uslu et al. (2021), feedback plays a crucial role in improving both the training program and the trainers themselves. The potential for feedback also significantly boosts participants' motivation, thereby increasing the effectiveness of the training. Web-based training on the other hand offers its own benefits, such as allowing employees to engage in training at their own pace (Lacerenza et al., 2017). Additionally, this mode of training can be undertaken at any time and from any location worldwide. Thus, as previously concluded, training should be multifaceted, combining on-site and web-based methods to capitalize on the advantages of each approach. Some theoretical training can be effectively conducted online, serving as a preparation for an on-site workshop. This approach aligns with the theory of spaced repetition presented by Ibrahim et al. (2017).

Within the literature, conflicting findings were done between short intensive training and low-intensity training over a longer period (Ibrahim et al., 2017; Uslu et al., 2021). Overloading employees with information is seen as the biggest risk when increasing intensity of the training which also was found in the interviews. On the other hand, short periods of training increase the motivation of participants which is a big factor in the amount of learning achieved (Uslu et al., 2021). Thus, training should be structured in a way that optimizes these factors. Short frequent training to sustain high motivation from participants while not overloading them with too much information. By increasing the frequency of training, each session could be shorter which reduces the risk of overloading while allowing for repetition. This type of training was discussed in the concept of TWI, section 2.9.1, where

the proposed training strategy should be performed on a daily basis but only for a maximum of two hours (Dinero, 2010; Soltero, 2004). Due to Northvolt's high workload, daily training could be problematic for current employees due to time limitations. Despite this should daily training be included for new employees as investments in their development will greatly impact productive over time.

To leverage the findings that shorter and intensive training sessions increase motivation when multifaceted teaching methods are used, learning factories could be utilized effectively. Learning factories are used to teach new employees in a controlled environment where complexity is reduced (Kipper et al., 2021). This idea was mentioned by several interviews as it combines theoretical training with practical training on actual machines. Thus, learning factories could be used as a first introduction to several required skills and knowledge before moving to real production facilities. However, the cost of learning factories is massive as it requires multiple machines to be installed and not fully utilized to increase production volumes. To combat this problem, production lines not currently in use for customer production could be used as training facilities. These are mainly lines under construction and not fully operating. By introducing new employees into this controlled environment, they will acquire the confidence to participate in real maintenance jobs when moving into real production. Several interviewees acknowledge the problem of new employees not having the confidence to make decisions and carry out maintenance tasks.

The conducted interviews showcased a desire to lengthen training to increase learning before entering the factory. This is mainly due to the complexity of maintenance; problems or failures can occur in multiple ways and it is impossible to prepare for all of them. Compared to production where there is only one way a machine should be used, maintenance is vastly more complex. Due to this are training structures created for production not suited for maintenance. Thus, a good structure must combine standardized processes to ensure quality while being fluent enough to equip people with the right tools to handle countless different challenges.

In conclusion, training should be multifaceted in the form of different types of teaching techniques such as theoretical and practical. Due to the different advantages between web-based and on-site training both could be used but a majority should be on-site. Further, training intensity must be balanced to keep participants motivated while not overloading or neglecting opportunities for repetition. Lastly, the structure used must combine standardization and flexibility to handle the complexity of maintenance.

5.2.2 Proposed training structure

Based on the above discussion an alternative training structure should be implemented to ensure a competent workforce at Northvolt. The structure must be created with the complexity of maintenance in mind and should therefore have a combination of standardized processes to ensure quality while flexible enough to

adapt to multiple complex situations. Furthermore, the structure should be able to handle Northvolt's need and ambition for expansion. To succeed with this a three-part training structure is proposed.

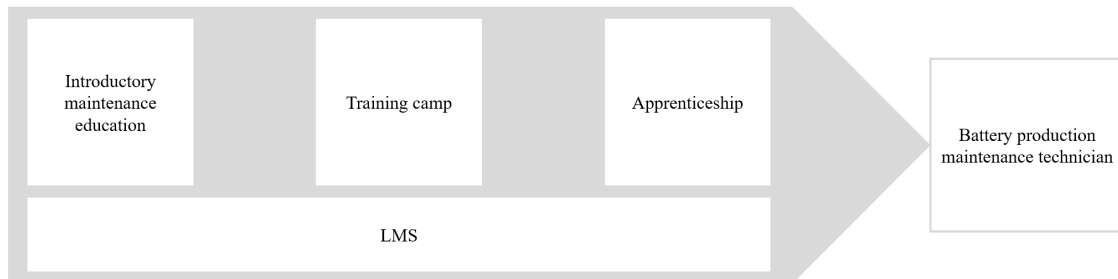


Figure 5.1: Overview of proposed training structure.

Today introductory maintenance education (IME) is a collaboration between Northvolt and the municipality of Skellefteå. In this program, participants are taught some basic mechanical skills and troubleshooting. Simultaneous to this LMS courses are performed to ensure that safety standards are known by all employees at Northvolt. LMS will continue during the whole training structure with different intensities depending on several factors discussed in section 5.2.2.4.

The combination of IME and LMS courses gives a foundation for employees without previous experience in maintenance or mechanical-related work. However, the interviews revealed that this training is insufficient, as it only imparts general competencies and does so ineffectively. To complement IME and continue to teach employees industry and firm-specific competences, a training camp should be implemented. As presented above, this type of training has been proposed by both interviewees and literature (learning factories). Training camps allow for a combination of theoretical and practical training to be performed in a safe environment not impacting customer production.

Creating a production line exclusively for training is not always a valid option due to the massive cost it requires, instead, should existing yet-to-be-operational product lines be used. This will result in lower costs and provide training opportunities for the coming years as new production lines are continuously being built. By simulating a real work environment and combining it with theoretical teaching, learning effects can be maximized. Employees should after the training camp be able to enter the factory and work safely and handle the most important tasks but not fully autonomously but instead together with more experienced employees. The construction of new lines will eventually stop which could pose a problem, however, this marks the end of the unsteady state and should decrease the volume of recruiting necessary. Therefore, the need for a training camp should decrease alternatively if the need still exists a separate facility could be built.

The aim of the training camp is to provide the organization with employees able to

create value faster, although fully autonomous will not be possible to reach directly after this stage due to the complexity of maintenance. Therefore, a support structure should be implemented sequentially when employees are introduced to real factory settings. This structure is based on TWI and a trainee structure commonly used in other manufacturing industries (Dinero, 2010; Soltero, 2004).

To effectively integrate training into daily operations, employees should engage continuously in a mix of expert seminars, theoretical readings, and practical training. This integration is crucial as it combines regular work with ongoing education which increases the number of different tasks an employee can solve. The structure is aligned with TWI where training should be done frequently in short periods, 2-3 hours a day, and for the rest engage in regular activities as part of a maintenance team. The focus of training should be tailored based on three parameters: the most common equipment failures, individual employee preferences, and the specific needs identified within their work shifts.

5.2.2.1 The expert

To facilitate this approach in a practical work environment, the structure of TWI will be used and the role of "The expert" will be introduced (Dinero, 2010; Soltero, 2004). This new position within the organizational structure follows the position of technician. The role is designed for individuals who specialize in one or more processes and then leverage this expertise to educate their colleagues, enhancing the overall knowledge base of the shift. The thesis focuses on Cell Assembly a general area within battery production and is further divided into several processes. These processes should be narrow to not overload the expert and allow them to truly develop their knowledge within the processes.

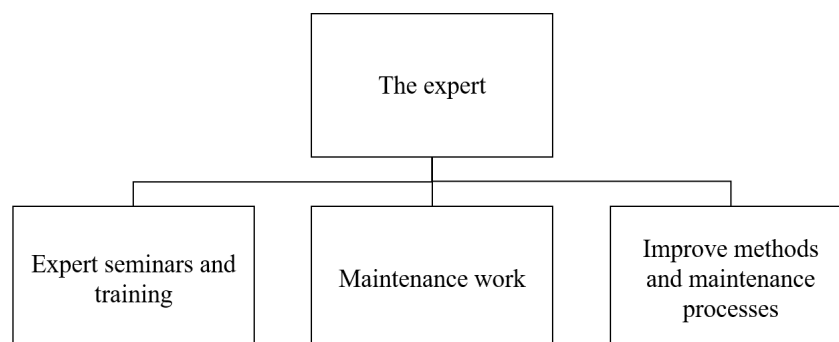


Figure 5.2: Tasks undertaken by the new role, the expert.

The training regime for these experts will align with the J programs of TWI focusing on both developing their knowledge and ability to teach other employees (Dinero, 2010; Soltero, 2004). The role will focus on three core responsibilities: educating others through expert seminars and personalized training sessions for technicians, improving working methods in collaboration with engineers, and fulfilling duties as a technician. This multifaceted role not only enhances individual skills but also contributes to the continuous improvement of workplace practices.

The expert should continue to be part of the maintenance technicians’ team and perform regular maintenance. This is important as the skills and competences should not be taken away from the core of the maintenance organization. TWI argues these tasks should be undertaken by the supervisor but due to the complexity of maintenance compared to production is it simply not possible to have one employee covering all areas (Dinero, 2010; Soltero, 2004). Instead, the aim should be to have multiple experienced technicians move to this role and undergo training in specific areas. The criticality of the area in terms of importance for production decides on the number of experts needed. A factor like the number of parallel production lines in a specific area could be one example of a determinant for the criticality of the area.

5.2.2.2 Learning in the training structure

The learning from the training should be structured as a cone, starting wide and progressively becoming more specific. This methodology begins by introducing new employees to a wide array of foundational topics and general concepts (Glaser and Bassok, 1989). The initial broad exposure is crucial as it provides a comprehensive background, allowing learners to understand the scope and context of the field. As the training progresses, the focus gradually narrows down to more specialized topics. This transition allows learners to build upon the broad knowledge acquired initially, applying it to more specific scenarios and problems. Therefore, the IME training should start with the general and most important basic skills for maintenance. For functional skills, it should be the basics of mechanical and electrical knowledge and how to use the most common digital tools. Interpersonal skills simultaneously learned should focus on how to communicate and troubleshoot effectively and the importance of continuous learning. This ensures recruits have a solid foundation when joining the training camp in the next part.

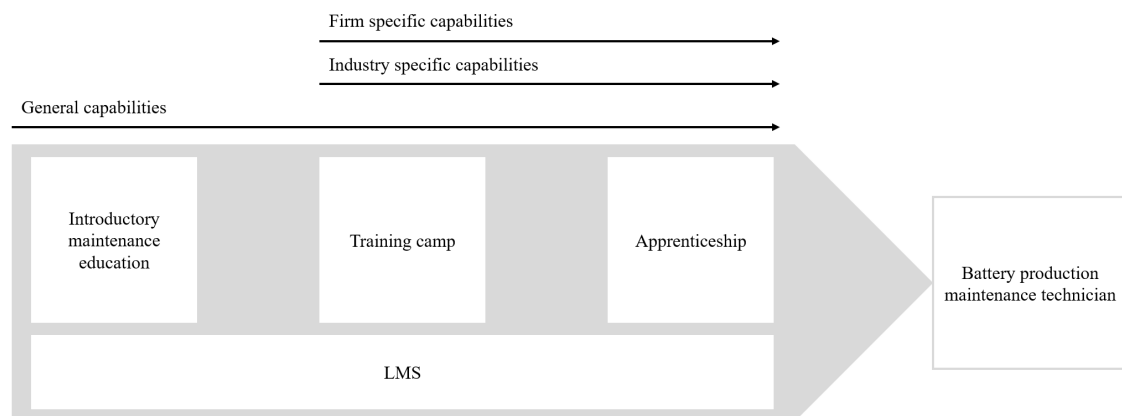


Figure 5.3: Overview of where specific capabilities are learned in the proposed structure.

The training camp should expand on the knowledge acquired at IME while also introducing new capabilities needed to succeed at Northvolt. For general capabilities this includes a deeper understanding of mechanical and electrical knowledge in this

specific industry setting, how teamwork is structured at Northvolt, and the rest of the necessary interpersonal skills mapped out in section 5.1.2.1. During this part of the training, both industry and firm-specific capabilities should be introduced to participants as these are essential to working safely in the factory. These include firm-specific safety protocols and work ethics, as well as industry specific knowledge of relevant machinery and the requirements of clean and dry rooms.

Lastly, after joining real production and working with more experienced technicians all knowledge and skills learned in earlier stages of the training structure should be applied in the real environment in the factory. Through the expert complex concepts and problems can be communicated in a simple and structured way allowing a deeper knowledge of important areas. During this part all baseline competences mapped out in section 5.1.2.1 should be known and well developed.

5.2.2.3 Experience affects training amount

Due to Northvolt's current rapid expansion increased recruitment of new employees is a necessity. New employees must also become autonomous as fast as possible to create value in the organization. This combination puts massive pressure on both the recruitment process and training structure to sufficiently supply the organization with competent new recruits. This undoubtedly affects who is recruited and employees within the maintenance organization have a diverse background including some with experience in maintenance and some that do not. To ensure safety all new employees must undergo some training but to optimize training and time to become self-sufficient in the factory the path should not be the same for all. Therefore, a decision framework has been developed to decide where in the training structure new employees should enter.

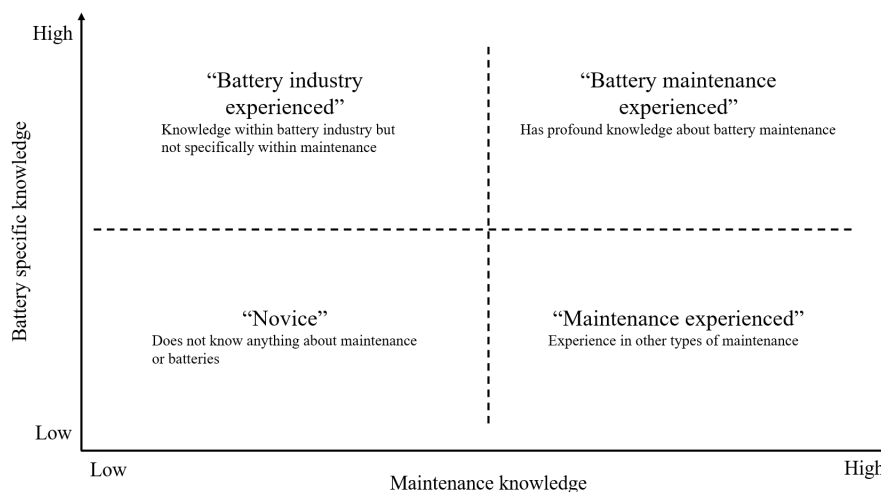


Figure 5.4: The four types of recruits.

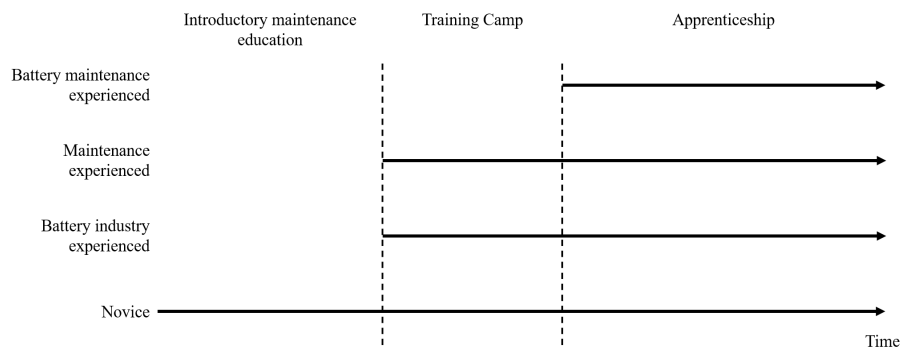


Figure 5.5: Where the different types of recruits join the training structure.

The framework is based on the individuals’ previous knowledge of maintenance and battery production. Employees with previous experience should not undergo the whole process as this takes time and does not bring much value for them or the company. IME is found to be good for people without previous experience as it allows them to gain some practical training with machines. However, for participants with experience this is far too basic and because it’s held by the public sector the machines are not related to battery production. As the process of IME currently is ten weeks the time saving from diversifying training based on preexisting experience could immediately save ten weeks of training per new employee with some experience.

Novices are employees who are not experienced in either battery production or maintenance. These will require the most training and time to become autonomous and therefore should participate in the whole process. Due to volumes currently being employed by Northvolt, this is an important group of potential employees. Battery Maintenance Experienced is the opposite of as they have previous experience in battery maintenance. These require the least amount of training as they only need to learn firm-specific knowledge before, they are ready to start working. Battery Maintenance Experienced are able to start working directly in the factory and participate as an apprentice. In Europe and Sweden are these types of personnel rare and therefore not a reliable source of employees.

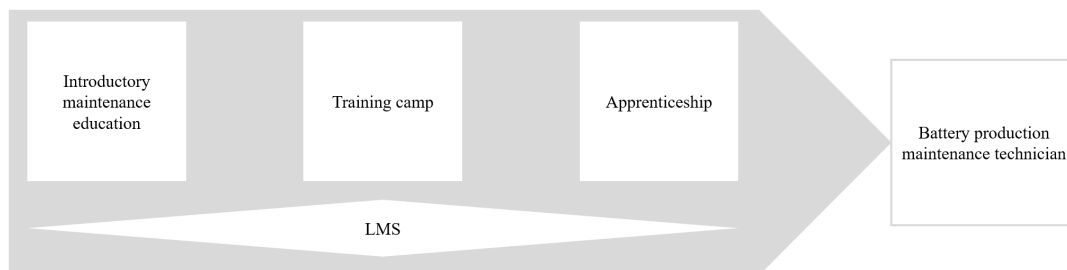


Figure 5.6: Training path for Novice.

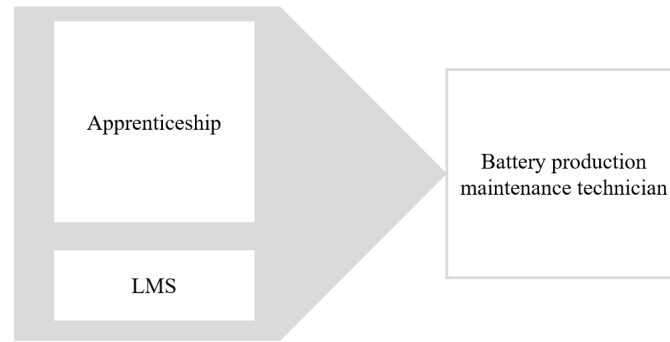


Figure 5.7: Training path for Battery Maintenance Experienced.

Between these two types are people with previous maintenance experience, Maintenance Experienced, and people with battery experience, Battery Industry Experienced. Due to their experience in a factory setting, they are able to start their training at the training camp and not necessarily participate in IME general training. As shown in the interviews are maintenance experience seen as positive because this increases your learning rate while having some mechanical and electrical skills. Other findings from the interviews were that people experienced with battery production have an easier transition to maintenance as they already understand the production when they start.

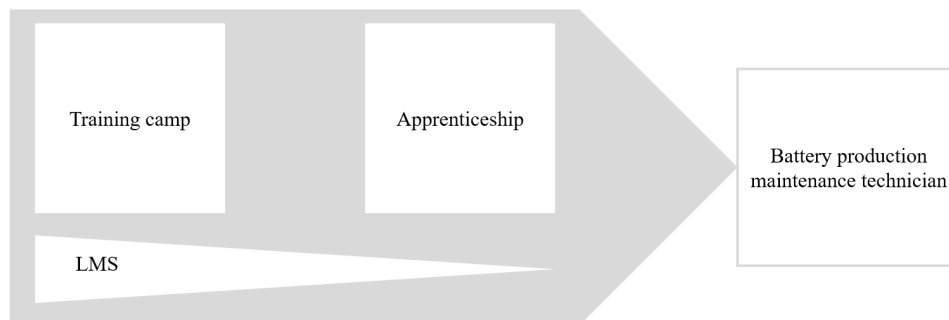


Figure 5.8: Training path for the Maintenance Experienced and Battery Industry Experienced.

By dividing new employees by experience and knowledge they can enter the training structure at different points resulting in short training time for some. This further allows Northvolt to understand who they are hiring and when they are expected to enter the factory and create value.

To decide where a person should be placed within the training structure a combination of self-evaluation and evaluation by human resource (HR) are proposed. The evaluation should include self-assessment in all necessary areas and showcasing of relevant certifications. This will be sufficient as HR should be able to spot people in either Novice or Battery Maintenance Experienced based on their self-evaluation, HR's own evaluation, certifications, and resume.

As highlighted by interviews the transition from operator to maintenance techni-

cian has been successful in the past. This could therefore be seen as a good source of maintenance technicians that only require a limited amount of training before becoming fully operational. This could create an alternative path in the organizational structure for operators seen as a potential promotion or at least a side-step. However, this could create tension between production and maintenance if this is portrayed as “stealing employees”. This also puts higher pressure on production as they need to recruit more people to compensate for the outflow to maintenance. On the other hand, the empirical data indicates a simplification for training operators, due to the repetitive nature of their tasks compared to maintenance technicians. Furthermore, Northvolt has developed and started to implement a training structure focused on positions within production. Therefore, this system of moving people from production to maintenance could be a valid solution if maintenance needs to scale up operations fast.

5.2.2.4 LMS throughout the training structure

LMS is an important part of the training structure as it provides theoretical courses and obligatory courses for safety and work methods. Depending on the classification of the new employee, presented in section 5.2.2.3, the volume of LMS courses changes. The obligatory courses regarding safety and work methods must be completed before entering the factory while theoretical courses regarding the machines and how certain tasks are carried out should be conducted in tandem with their practical counterparts.

For all new employees LMS courses should be conducted directly as they enter the training structure, the differences will be in intensity. For Novice, this means combining IME and the obligatory LMS courses. As they enter the training camp Novice should only perform necessary technical LMS courses together with practical training. Lastly, Novice will undertake LMS courses together with their apprenticeship, these depend on what is necessary for the specific area and machines used or specific skills necessary for the shift.

Maintenance Experienced and Battery Industry Experienced will undertake the LMS courses with a higher intensity as their path within the training structure is shorter. They should combine obligatory and theoretical courses during their period at the training camp. However, due to their previous experience some courses will not be necessary or only undertaken to ensure the existence of certain knowledge. Battery Maintenance Experienced will join directly as an apprentice which means they need to complete the obligatory safety and work method courses before entering the factory. After this, they should only perform the necessary courses as they should be able to perform the majority of tasks through their experience.

5.3 Repeatable methodological framework

The third research question states, "What are the steps required to maintain and update competence requirements in a maintenance organization at a battery manu-

facturer?". The reason to include this part is to enable battery-producing companies to perform this mapping in different areas than Cell Assembly or redoing the process due to changing circumstances, for example, development around digital tools, affecting the maintenance strategy. To answer the question a step-by-step framework is formulated that can be applied to all areas of battery production. The framework is simple and easy to use, increasing the probability of it being used in real life. Figure 5.9 visualizes the framework with the two last steps highlighted as the result of the framework.

Step 1 - Specify area of interest

Establish in what part of production the mapping should be conducted. Note what characteristics are unique for this area. The purpose of this stage is partly to realize in which area the mapping is going to occur, as well as to clearly define boundaries for the mapping. This establishment of part of the production should be defined both in terms of horizontal stretch (what parts of the production for example Cell Assembly or formation and aging) and vertical stretch (what roles will be included). Noting down characteristics could give some indication towards what capabilities will be specific for the area and what capabilities will be more important.

Step 2 - Plan interviews and data gathering

Before conducting the data gathering interviews should be planned and interview guides created. To gain a better understanding of requirements field study sessions should be included which could be in the form of shadowing employees during their regular tasks. Ensure to include interviews at all levels (blue and white collars). Use questions focusing on characteristics of the job performed and what capabilities are the most important to succeed in the area. See Appendix A for the interview guide used in this report.

Data gathering is the most critical activity affecting the outcomes of the work. If conducted poorly, it can negatively impact the results or, in the worst case, lead to outcomes that harm the company. Therefore, careful planning of data gathering is essential to ensure the quality of subsequent steps.

Step 3 - Gather data

Conduct the interviews and planned field study. Interviews should be recorded or transcribed if possible to ensure not losing data. The data gathering will be the source from which the capabilities will be derived. It is important to be objective in the data-gathering phase to ensure that no personal bias from the person conducting the interviews affects the result to ensure the result's validity. This phase will also benefit from studying and joining maintenance personnel for a day to further realize what challenges and characteristics define this specific area.

Step 4 - Analyze data

The fourth step aims at analyzing the results from the conducted interviews. It is important to find what capabilities are significantly mentioned. To do this a structured analysis method should be used to find patterns and repetitions. This

thesis utilizes a thematic analysis structure which codifies the findings into categories to compare. Depending on the data gathered other analysis structures could be used.

Step 5 - Categorize capabilities

When the capabilities are mapped out they should be categorized into general, industry-specific, or firm-specific competencies. Through this categorization, it is possible to determine where in the different training stages each capability should be trained, or if some capabilities should be required when being employed at Northvolt.

Step 6 - Incorporate findings into a training structure

To fully take advantage of the found capabilities each capability should be incorporated into the training program to make sure that each capability is taught. This step will be the final step in identifying, mapping, and training capabilities necessary in different areas of the maintenance organization. This will ensure the findings generate value for the company by showcasing how they should be trained.

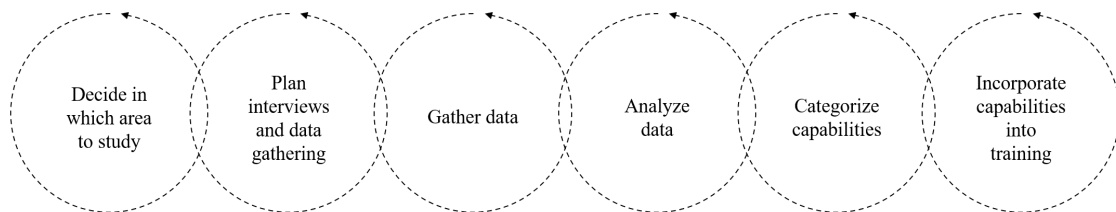


Figure 5.9: Visualization of mapping and utilization of capabilities for maintenance.

It is important to realize two things about this framework. First, this is a flexible framework that can be tailored to fit different circumstances and specific requirements from different areas of the maintenance organization. The steps each represent individual goals that should be achieved, however, it is not necessary to use the specific methods suggested in the letter. Instead, the framework should be used as a frame of reference to ensure all necessary steps are included. Secondly, each step can be iterative to fully achieve the goal with each step in combination with having some overlap between the steps. Figure 5.9 highlights how each step in the process is sequentially overlapping while being iterative within each step.

6

Discussion and implications

To extend the reasoning begun in the chapter 5, this chapter will have a wider perspective discussing findings from the study. Capabilities in maintenance in general as well as in battery manufacturing maintenance are discussed together with Northvolt's volatile scaling phase, training, and future research.

6.1 Capability within a maintenance organization

The effects of the fourth industrial revolution have been prominent for maintenance organizations across industries. The call for capabilities within IT, data analytics, and other digital systems has emerged as a result, switching from mainly needing mechanical skills in a maintenance organization (Benhamza Hlihel et al., 2024). IT development, implementation, and maintenance have emerged to be crucial to succeed within maintenance (Kipper et al., 2021). This need for more advanced IT-related capabilities could be derived from the fact that factories are becoming smarter and more digital, integrating more advanced IT-systems. Capabilities have therefore changed across industries for the whole maintenance organization, however as previously discussed in chapter 5, capabilities needed from technicians will probably not differ that much from the current situation. Despite integrating more IT-systems, moving parts such as ball bearings, belts in production, and electrical components will still have to be maintained and changed eventually. Consequently, technicians will probably still need to perform traditional maintenance tasks, while gaining an understanding of how the systems operate and affect the function of machines.

However, engineers, managers, and supervisors will experience a greater change in terms of the capabilities needed to perform their jobs. As engineers are a part of setting up machines and creating work instructions, personnel in this position will have to have a greater knowledge as well as capabilities within IT. The changes created by Industry 4.0 and Smart Maintenance will therefore fall on these positions rather than on technicians. While this thesis has put great emphasis on how the role of a battery maintenance technician will develop, the discussion regarding white collar roles has been more scarce. The thesis recognize that the discussion in terms white collar development could be further investigated in the context of Smart Maintenance. However, this discussion will not be extended in this thesis.

6.2 The battery industry vs traditional manufacturing

The battery industry is in many ways a unique industry facing challenges that a majority of traditional industries does not. The interplay between a new type of industry that the Li-Ion battery industry is and an extraordinary scaling pace is creating situations that are unique for Northvolt. However, scaling it down to the maintenance organization the differences seem quite slim. The interviews strongly suggest that the differences in working with maintenance within battery production are similar to maintenance within other production industries. Machines need to be maintained and the methods for this do not significantly differ from other industries, with some exceptions. As discussed previously in chapter 5 the call for cleanliness to minimize the risk of contamination is taken to a level that is quite unusual for manufacturing companies (Rahimzei et al., 2018). The result is a call for special caution when performing maintenance, differentiating the battery industry from for example the automotive industry. The combination of high-volume production and chemicals also indicates some uniqueness within the battery industry. As parts of the production are made up of chemicals in a fluent state that later transforms into solid state batches are also significantly different from many traditional manufacturing industries.

Despite the differences mentioned, the impact in terms of capabilities needed within the maintenance organization is marginal. This is clearly shown by the number of general competencies compared to industry- and firm-specific. The implication of this is that the European battery industry will be able to collect competent personnel outside of the battery industry, partly from other industries and partly from educational institutes. Problems with scarcity of maintenance personnel could therefore be derived from the characteristics of the region where the manufacturing plant is located, rather than too specific requirements for maintenance personnel. The difficulties faced by Northvolt Ett to find competent maintenance personnel could therefore be explained by the limited workforce provided by the region of Skellefteå. However, other potential battery production facilities located in more populated areas with preexisting large industries will most probably experience less of this problem. Despite this, the region itself cannot be blamed solely on the scarcity of maintenance personnel. A general shortage of maintenance technicians is seen over numerous sectors (The Powers Company, 2024). The problem will therefore not evaporate for battery production facilities in more populated areas. The limited access to maintenance technicians will still be relevant but not as prominent as in the north of Sweden.

Another aspect to mention is that even if the general competences are the same across industries they all include some specific elements. Mechanical competence allows you to learn much quicker but the recruit still needs to learn what type of specific components is used. This means Northvolt needs to develop training to learn the specifics of general capabilities and not only industry- and firm-specific capabilities.

6.2.1 Comparison to the ALBATTs project

The ALBATTs project presented in section 2.8 has been disregarded to a large extent in this report due to two reasons. First, the definition of the different roles found in other literature better aligns with the definition of roles found at Northvolt, compared to the definitions made by ALBATTs. ALBATTs did for example include quality control in their description of maintenance engineers, something not found to be the case at Northvolt (Project ALBATTs, 2023b). Second, the source for the competencies presented in ALBATTs is the ESCO database created by the European Commission (Project ALBATTs, 2023c,b). A decision was therefore made to use the ESCO database directly instead of ALBATTs interpretations. This decision also limits the number of steps away from the original source, ensuring a strong connection to data-driven maintenance strategies such as Smart Maintenance, and mapping the necessary competencies for maintenance staff.

6.3 Implications of Northvolt's volatile state

Interviews highlight another phenomenon placing Northvolt in a unique situation compared to the majority of industries in Europe. Northvolt was founded in 2016 and started building its first gigafactory, Northvolt Ett in Skellefteå, in 2019. Since then the company has expanded and has reached more than 5300 employees, January 2024 (Northvolt, 2024a). The pace of scaling has been rapid resulting in a quite volatile state with constant change, both overall in the company but also at Northvolt Ett. Rapid expansion calls for hiring at a fast pace which creates a volatile stage characterized by constant change. However, this stage is going to end and will transform into a stable phase when the factory in Skellefteå is finished. When this stage is reached the conditions will change. The need for rapid hiring due to expansion will decline and will create a calmer environment, both for current employees as well as for new employees. The maintenance organization will experience less stress when training new employees and could therefore put more effort into training to ensure qualified new employees. At this phase, Northvolt has the opportunity to keep moving the maintenance organization toward Smart Maintenance. This will be a time-consuming process to implement at the full maintenance organization, however, it is likely that it will move quicker as a steady state is reached.

6.4 Relative importance of capabilities

The qualitative nature of this thesis disables the opportunity to quantify the relative importance of the found capabilities. However, some reasoning can be done on the subject. Connecting to the previous section, some capabilities highlighted in the empirical findings are more important during the volatile stage that Northvolt currently operates in, compared to when Northvolt enters the steady state. The motivation for skills like personal drive is due to the endless ways a machine could

fail. This is exaggerated in a volatile phase during rapid scaling as multiple tasks are often needed to be solved. In the volatile phase, personal drive will be crucial to evolve in the company and to drive the maintenance organization forward. Therefore, this capability could arguably be more important in the current state than in future states.

Similarly, some capabilities will be of more relevance when implementing Smart Maintenance compared to when Smart Maintenance is up and running and the situation calls more for maintaining it and updating structures and programs that are the foundation of the implemented concept. Setting up the data-driven support systems that are needed will demand different capabilities compared to maintaining and updating them, putting a stronger emphasis on data analytical skills and digital tool understanding in the early phases of this implementation compared to when a steady state of Smart Maintenance is reached. Further, when succeeding with both internal and external integration, as they are two of the four parts of Smart Maintenance, some capabilities relating to communication and teamwork will have a more decisive role compared to when the integration is more established. Initiating contacts and setting up collaborations both internally and externally of the organization.

This suggests that, beyond the varying importance of different capabilities, there is a need to continually update skill matrices to align with the evolving prerequisites in the operational environment. Some capabilities might be crucial at a certain point in time to then decrease in criticality or vice versa. To maintain these matrices and to have a structure and routine will be essential to ensure that the right preconditions are in place to maintain the required competencies in the maintenance organization.

6.5 Training general discussion

According to Tiwari and Saxena (2012) is human resource management one of the key activities to sustain a competitive advantage compared to competitors. A skilled workforce requires investments but the set of skills, competences, and capabilities withheld by personnel is not easily copied by other companies. Therefore, investments in training should be prioritized for all departments to ensure the necessary skills, competences, and capabilities are achieved by the workforce. Investments in training could potentially generate trust between employees and employers as this indicates the value of a competent workforce is recognized by upper management.

Furthermore, successful training has other positive implications for the company. According to Elnaga and Imran (2013) is another positive effect the increase in motivation. Being able to perform the job well results in higher satisfaction with the job and therefore creates increased motivation. This increase in motivation could have further positive impacts such as spreading a good work environment, helping colleagues with problems, or participating in extra activities such as after work or company sports teams.

Nevertheless, the approach to investing in training remains unclear. Unlike technological upgrades, feedback on training effectiveness is often delayed. It takes time to develop a competent workforce which makes the investments long-term and sometimes risky. This problem increases today as many industries currently transition to more data-driven and digitalized operations. Organizations must, consequently, not only invest in a training structure that takes time to generate value but also understand what competences are important today and in the future.

Another aspect not discussed extensively in the report is the phenomenon of skill decline. Without proper training and the opportunity to utilize the competences the learning will eventually fade away. This poses as a risk for firms as some competences are expected to exist within the workforce but due to inactivity could have been exposed to skill decline. According to Ibrahim et al. (2017) is multifaceted training important to combat skill decline as it has shown to increase the retention of knowledge over a longer period of time. Furthermore, organizations could combat this problem by regularly testing their workforce on certain competences to ensure their existence. However, this could be seen as a mistrust between employer and employees which could affect the moral of the workforce negatively.

6.6 Expanding the role of the expert

The use of an expert role is elaborated in section 5.2.2.1. However, beyond the initial discussion, the role of the expert could be expanded into a role that decreases the risk of skill decline in a shift and ensures that the general knowledge of a shift is steadily increased. Expert seminars could primarily be aimed at introducing inexperienced employees to specific maintenance routines at certain processes and machines, while the role could encompass more advanced seminars aimed at challenging and developing experienced employees. Beyond achieving higher competence in shift, the expert role could further positively impact employees in the maintenance organization. First, the clear development path for individuals within the maintenance organization could serve as a motivational factor. Basic behavioral theory indicates that personal development is one of the more important factors in creating motivation. Second, the expert role could be a clear target to achieve for more experienced technicians who are looking for development and promotions. These two factors could together lead to less personnel turnover, further gaining Northvolt.

6.7 Research methodology discussion

The master's thesis was conducted during the spring of 2024 and structured in three phases. The phases were created to guide the work and clarify the time frame for all activities. The first phase focused on creating a foundation for the rest of the research by conducting open interviews and a general literature study on relevant subjects. The second phase followed the same structure of interviews and literature research but narrowed the scope based on the findings of the first phase.

Furthermore, the second phase also included observations of a maintenance team within Cell Assembly. Lastly, the third phase included the majority of data analysis and framework creation. Some complementary interviews were held to iterate the frameworks and validate the findings.

The structure allowed for a robust approach to the problems, with a wide scope that continuously narrowed as new findings emerged. However, the initial phase could be shortened to either extend the second and third phases or reduce the total project duration. This could positively impact the project by allowing for a more extensive in-depth phase (phase two), potentially leading to an increased number of interviews, which would further enhance the validity of the results. On the other hand, shortening the initial phase could increase the risk of overlooking relevant subjects and concepts, which might hinder the subsequent steps.

Compared to the structure outlined in the initial plan, there have been no significant changes, only adjustments to the time frame of some activities. These adjustments were necessary to complete the thesis on time and create a better workflow. Some problems setting up interviews have occurred, mainly due to lack of response, but with the help of the thesis supervisor at Northvolt, the majority of planned interviews were conducted.

In retrospect, some changes could have been made for a potential improvement of the research. First, a more comprehensive data gathering could increase the validity of the findings. This could include both conducting additional interviews and observations. Second, during the third phase, a seminar with several technicians was discussed to generate feedback on drafts of the capability mapping and training structure. This could have resulted in valuable insights but, due to time constraints and multiple successful feedback interviews, this was decided to not be included.

6.8 Ethical, societal, and ecological aspects

Ethical aspects of the project concerned how data and information could be gathered in a secure and valid process. This included how anonymity was handled to ensure interviewees could be protected and Northvolt as a company if sensitive information was shared. Due to these concerns, each interviewee was asked before if they accepted the interview to be recorded, and a discussion with the supervisor from Northvolt was held to ensure no sensitive data was shared with the public.

Northvolt could have a substantial effect on the design of practical maintenance education, IME, in Sweden as one of the leading industries. Northvolt is a pioneer within battery manufacturing in Europe, meaning that they have the opportunity to form standards and develop maintenance education for modern industry in Sweden and in Europe. If Northvolt formulate clear training structures and define what is expected from each step in the education of a maintenance technicians, they can shape and formulate how practical maintenance training should be designed. Northvolt has therefore the opportunity to help shape education, an important part

of society, and this report could lay the foundation for outlining important aspects of maintenance training for Industry 4.0 and beyond.

As this thesis intends to enable Northvolt to create a foundation for the implementation of Smart Maintenance, this thesis could be argued to have some positive effects on the environment. If maintenance performed is streamlined through Smart Maintenance it could have some positive impact, both economically and environmentally. If implemented correctly, better predictive maintenance could lead to less downtime, less consumption of spare parts and higher utilization of the factory. Correctly maintaining machinery could also lower the risk of failures that could lead to hazardous spills or unsafe situations for employees. Less consumption of spare parts directly impacts the environment, while achieving higher up time could be argued to indirectly positively impact the environment as battery production is a substantial part of the green transition. However, this thesis has entailed two trips to Skellefteå to conduct empirical data gathering. These trips was considered to be necessary to conduct interviews but also to perform observations of the work structure and environment of the maintenance team in Cell Assembly at Northvolt Ett.

6.9 Future research

The battery industry is still a relatively young industry in Europe. Research material on the subject is very limited, especially relating to the maintenance organization. The list below are suggestions of further research to be conducted to create a more covering research substrate.

1. **Fast scaling battery industry:** As battery manufacturing is a combination of continuous, mass, and batch production, it is inherently different from traditional manufacturing, for example, automotive manufacturing. Additionally, Northvolt is scaling at an incredible pace further making the situation more complex. What this means in terms of maintenance is yet to be established. Further research regarding how these factors affect maintenance in different parts of battery manufacturing is needed to establish consensus within the industry and to pave a path forward for additional battery manufacturing plants in Europe.
2. **Increase of demand creating shortage of maintenance personnel:** The combination of continuous production, mass production, batch production, and fast scaling will most probably not be unique for Northvolt in the future. Each year is 1,2 million cars and 500,000 trucks produced in Europe and if a substantial part is supposed to be transformed into electric vehicles the demand for batteries will grow rapidly. Additionally, battery storage is an increasingly hot topic as it could help the transition towards green energy production, something that will increase the demand for batteries even more. This will likely increase the number of actors in the battery manufacturing industry in Europe, further increasing the shortage of maintenance technicians. Further research regarding how this shortage should be overcome is necessary.

3. **Competence mapping for maintenance organizations:** As work on this report has progressed, a lack of research regarding optimal ways of mapping competencies for maintenance organizations has been prominent. A consensus regarding the optimal abstraction level and complexity of competence mapping seems to be lacking, something that could hamper optimal maintenance organizations. This subject calls for additional research, especially considering data driven maintenance structuring as Industry 4.0 is having a growing impact on manufacturing and enabling Maintenance 4.0 as well as Smart Maintenance.

4. **Defining the expert role:** The role called the expert that is suggested in this report is not clearly defined in terms of work instructions, what part of the organization to belong and how the role should be developed when a company within the battery industry reaches a steady state. To develop and concretize the role some further research has to be done, where learnings and inspirations can be taken from other industries, for example, the automotive industry. This research helps create a more efficient and capable maintenance organization within the battery industry.

7

Conclusion

This study aimed to evaluate capabilities needed for Smart Maintenance within European battery manufacturing organizations, using the Swedish company Northvolt as a case study. Three research questions were formulated to guide the investigation. The first question required mapping the Smart Maintenance capabilities specific to battery manufacturing. As detailed in section 5.1, our analysis yielded three extensive lists of capabilities. These lists are tailored to distinct professional groups: blue-collar workers (technicians and team leaders), and white-collar employees (engineers and planners in one category, and managers and supervisors in another). The capabilities are categorized into general, industry-specific, and firm-specific types. The analysis shows that the majority of all capabilities found are general capabilities, indicating that maintenance needs in battery manufacturing do not significantly differ from those in other sectors.

The second research question focused on developing a targeted training outline for Northvolt's maintenance personnel to utilize mapped capabilities. This training framework is specifically designed to equip new employees with the essential skills required to meet both the unique and general demands of the industry. The proposed training outline takes into account the varying levels of experience and knowledge that new hires bring to Northvolt. Consequently, each employee is individually assessed and categorized into one of four levels: Novice, Battery Industry Experienced, Maintenance Experienced, or Battery Maintenance Experienced. Depending on their initial categorization, new hires follow one of three tailored training pathways that maximizes the efficiency of the training process. This approach ensures that each employee is equipped with the necessary skills and knowledge to effectively contribute to the manufacturing facility. By doing so, the training framework not only enhances individual competencies but also supports the broader organizational goal of operational excellence.

The final objective of this paper was to develop a practical framework to facilitate capability mapping for Smart Maintenance. The framework introduced is straightforward yet effective, designed to be performed efficiently even with constrained time and resources. This methodology can serve the battery industry significantly, not only by enhancing understanding of specific capabilities within various company areas but also by facilitating updates to existing capability matrices. As both the company and its environment evolve, this adaptable framework ensures that capability assessments remain current and relevant, thereby supporting continuous improvement.x

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A

Semi-structured Interview Guide

Interviewee: _____

Position: _____

Are we allowed to record the interview? _____

1. What are your main tasks at Northvolt?
2. How long have you been at Northvolt?
3. What is your past experience before joining Northvolt?
 - (a) Depending on the answer: How is the work different from the work you do today?
 - (b) Depending on the answer: Would you say that maintenance in battery production is significantly different from other industries? If so, how?
 - i. Potential follow-up: What do you think the differences are between maintenance in battery production and other industries?
4. Could you describe how a maintenance call is handled?
5. What technical skills do you need in your daily work?
6. What soft skills do you need?
7. What skills do you believe are important but you are not able to utilize at Northvolt today?
8. What skills would you like to see in the future in the maintenance organization?

Manager/Supervisor

1. Are you/Northvolt currently working with data-driven decision making?
2. Why are you not using data-driven decision making to a greater extent than you are?
3. How could this be fixed?
4. What are the benefits from data-driven decision making within maintenance?
5. What competencies do you think are important to have to use data-driven decision making in the future?
6. Are employees expected to know these when starting at Northvolt?
7. Are they taught at the academy today?

Technician

1. Can you describe the training process that you underwent when joining Northvolt?
2. What are your thoughts on the training/onboarding?

A. Semi-structured Interview Guide

- (a) What was good?
- (b) What was bad/could be better?
- (c) What was missing from the training/onboarding?
- (d) What was unnecessary in the training/onboarding?

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