Identifying key objectives when going through a Digital Transformation

An Extensive Study within the mining industry

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ABSTRACT

Digital technologies and their significance to society has caused their existence and impact to be referred to as entailing a digital revolution. For businesses, digitalization is the use of digital technologies to create new business models and value-adding activities. The use of digital technologies can in turn result in possible improvements of several areas e.g., productivity. The possible outcomes entail a new playing field for profit-driven companies who all have the common denominator to constantly maintain a competitive edge. To fully utilise the digital technologies, businesses need to take actions in the organization to embrace new services and streamlined processes from the use of digital technologies, with other words go through a *digital transformation.*

The purpose of this master thesis was to describe and analyse production processes to identify key objectives for a company going through a digital transformation. In a digital transformation, many organizational areas need to interplay with the intended use of digital technologies, this study focused on investigating production processes to contribute with key objectives within this area for a company going through a digital transformation.

The purpose was intended to be satisfied with the help of two theoretical models. The first to describe and visualize the production processes, the other to analyse the digital readiness of the production processes and to extract key objectives to go through with the transformation. The research purpose was both descriptive and exploratory and to fulfil the purpose, a case study was used to investigate one production process at the case company. The research method was qualitative which can be reflected in the data collection approach that was conducted through interviews and observations as well as archive analysis on documents received from the case company.

From the results and analysis, it became clear that the theoretical model used to describe the production process, value-based process modelling, was an efficient tool to both get a comprehensive view of the process and its activities as well as a basis for in-depth descriptions of each activity. Furthermore, the second model, IMPULS, was adjusted to fit the purpose of this study. The resulting digital readiness of the case company process was of a “Learner”. Furthermore, by combining the two theoretical models, the key objectives in production processes for a Learner were identified for the company to go through a digital transformation. These were to *understand the full potential of collected data and use it optimally; enable full potential of equipment by integration;* and to *simplify and improve the flow of information.*

SAMMANFATTNING

Digitala teknologier och deras betydelse för samhället har orsakat att deras existens och påverkan kallas för en digital revolution. För företag medför digitaliseringen att affärsmodeller och värdeskapande aktiviteter behöver modifieras. Användningen av digitala teknologier kan resultera i möjliga förbättringar inom flera områden, t.ex. produktivitet. De möjliga fördelarna innebär en ny spelplan för vinstdrivande företag, som alla har den gemensamma nämnaren att ständigt behålla en konkurrensfördel. För att kunna utnyttja de digitala teknologierna fullt ut och omfamna de nya tjänsterna och effektiviserade processer, måste företagen vidta åtgärder i organisationen. Företagen måste genomgå en *digital transformation*.

Syftet med det här examensarbetet var att beskriva och analysera produktionsprocesser för att identifiera huvudmål för ett företag som genomgår en digital transformation. I en digital transformation behöver många organisationsområden samverka med den avsedda användningen av digitala teknologier. Det här examensarbetet fokuserade på att undersöka produktionsprocesser för att identifiera huvudmål för ett företag som genomgår en digital transformation.

Syftet var avsett att uppfyllas med hjälp av två teoretiska modeller. Den första beskriver och visualiserar processer, den andra analyserar processers digitala beredskap och hjälper till att extrahera viktiga mål för att genomgå transformationen. Forskningsändamålet var både beskrivande och utforskande och för att uppnå syftet användes en fallstudie för att undersöka en produktionsprocess hos fallföretaget. Forskningsmetoden var kvalitativ vilket kan återspeglas i den datainsamlingsmetod som genomfördes genom intervjuer och observationer samt arkivanalys av dokument som erhållits från fallföretaget.

Från analysen blev det tydligt att den teoretiska modellen som används för att beskriva produktionsprocessen, värdebaserad processmodellering, var ett effektivt verktyg för att både få en övergripande bild av processen och dess aktiviteter samt en grund för djupgående beskrivningar av varje aktivitet. Dessutom justerades den andra modellen, IMPULS, för att passa syftet med denna studie. Den resulterande digitala beredskapen i fallföretagets process var av en "Learner". Dessutom, genom att kombinera de två teoretiska modellerna, identifierades huvudmålen i produktionsprocessen för en Learner som genomgår en digital transformation. Dessa var att *förstå den fulla potentialen av insamlad data och använd den optimalt*; *möjliggör utrustningens fulla potential genom integration*; och att *förenkla och förbättra informationsflödet*.

ACKNOWLEDGEMENT

This master thesis was written during the spring semester of 2021. The master thesis marks the completion of the author's studies. We, the authors Albin Nyström Eklund and Axel Adelgren, have studied MSc in Mechanical Engineering, specialising in Supply Chain Management. The thesis is written with a pervading collaboration between the authors from beginning to end. Hence, both has contributed equally to all sections in the report.

First of all, we would like to direct a warm thank you to our supervisors at LKAB, Petter Forss and Gurmeet Shekhar, for giving us the opportunity to write our master thesis in collaboration with you. Your knowledge and experiences from various parts within LKAB facilitated our understanding and made the study interesting the entire time. Lastly, thanks for all the efforts to make our working environment as good as possible. Also, thank you to Atif Waheed for our weekly meetings at the beginning of our work that provided us with insights and deepened understanding through interesting discussions.

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Albin Nyström Eklund

Lund, 25th May 2021

Axel Adelgren

Lund, 25th May 2021

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF DIAGRAMS

1 INTRODUCTION

This chapter aims to introduce the reader to the subject of the thesis. First, the background for understanding the issue, its relevance, and why the research is needed is presented. Second, the purpose of the thesis is presented with its delimitations.

1.1 Background and Problem Formulation

The digital revolution, described as the shift from mechanical and analogue electronic devices to the digital technology available today, is by many named the third industrial revolution (Clarke, 2012; Degryse, 2016; Ministry of Enterprise and Innovation, 2016; Schwab, 2015; The Economist, 2012) The new digital technologies imply a radical change for societies and businesses.

The digital revolution has involved different terms describing concepts related to digital technology, namely digitization, digitalization, and digital transformation. The oldest word is *digitization*, defined by the Gartner IT Glossary as "the process from changing from analogue to digital form, also known as digital enablement".

Further, *digitalization* is described as a significant trend that will impact on the world economy and other parts of society (Blix, 2015; Ernst & Young, 2020; Semerikov et al., 2019). According to the Gartner IT Glossary, the definition of digitalization is "the use of digital technologies to change a business model and provide new revenue and value-producing activities; it is the process of moving to a digital business". Three phases can describe the digitalization process for businesses. An initial phase where single operations or processes are automated, followed by a mid-phase when related processes are automated and joined together. The last phase is the integration of multiple systems that support processes and information flows into management systems. The last phase is the most complex due to the challenge of fully integrating systems and making them interoperable. (Savić, 2019)

Digitalization is to be separated from *digital transformation* despite the large extent of interchangeability in the literature. Digitalization entails a digital transformation that impacts behaviours in society, reaching from communication and shopping to entertainment and health (Savić, 2019). In the industry, the application of digital technologies affects how businesses are conducted. Modified value chains and re-structures in business culture and business strategies are required due to digital technologies enabling new services and streamlined processes. (Ebert & Duarte, 2016; Parviainen et al., 2017). The structural transformation necessary for businesses due to digital technologies has been recognized as the most pervasive managerial challenge for companies in the coming decades (Nadkarni & Prügl, 2020). Going through a digital transformation is about understanding that digitalization is not a support function. Instead, it is a strategic key competence for development and competitiveness.

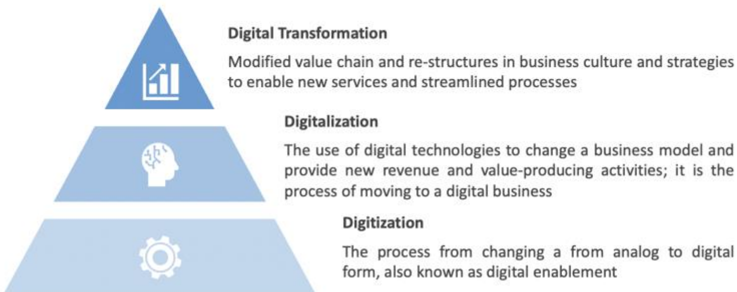

Figure 1. Illustration of the concepts described. Digitization, digitalization and digital transformation.

Even though the digital revolution has been ongoing the last decades, the Swedish Agency For Growth Policy Analysis (2016) underlines a dramatic acceleration of digital transformation. The increased availability of calculation capacity and decreasing prices in data storage creates opportunities to utilise big datasets. It results in the need for information and communication technologies such as Internet of Things (IoT) and Artificial Intelligence (AI) to manage big data. (Swedish Agency For Growth Policy Analysis, 2016)

Datasets of organizations have become so large that the traditional database management systems are insufficient for working with the data efficiently. The big datasets are described by the term "Big Data". (Elgendy & Elragal, 2014). IoT describes a system handling high volumes of data on the internet. The data is collected and measured in real-time from connected end devices (Hamdy et al., 2018). The capability of IoT is utilised to a high degree when converged with AI. The gathered data from IoT devices can improve and train AI algorithms. The algorithms are then utilised as an analysing tool to yield insights into problems and make predictions and operational decisions across many business areas. The three phenomena thus form an *ecosystem of automation*. (Adi et al., 2020; Towers-Clark, 2019).

The effects of digital technologies are thought to provide benefits in a wide range of aspects. It is in every business's nature to gain the most output from its performed activities. Regardless of if the business value proposition is of delivering products or services to the market, a common denominator for established organizations is that they are constantly looking for ways to maintain a competitive edge. The usage of emerging technologies that digitalization entails changes the playing field for businesses and implies structural transformations. (Lichtblau et al., 2015)

One of the main opportunities with digitalization is to improve productivity. By investigating current processes and simplifying these using, e.g., information technology or automation, companies can achieve improvements in operational productivity and efficiency. Resulting in enhanced competitiveness and revenue growth. (Fatorachian & Kazemi, 2018; Swedish Agency For Growth Policy Analysis, 2016) Big data and IoT can be used to improve performance measures that enable quality assurance and continuous improvement and development. AI can be used for automating such analysis previously performed by a specialist. According to Blix (2015), the main driving force for automation is increasing quality, producing new products, and reducing costs. Further, digital technologies can increase resource efficiency and energy savings using smart grids and demand management (Fatorachian & Kazemi, 2018; Parviainen et al., 2017).

Another opportunity is to improve safety and working conditions by automating hazardous processes. According to Swedish Work Environment Authority, the most common work-related accidents occur due to lost control of machines, fall injuries, or movement with loads (Swedish Work Environment Authority, 2020). By utilizing new technology and using automation, these accidents are thought to be able to be reduced (Blix, 2015). Although the potential benefit of reduced accidents, Lee et al. (2019) show that safety accidents in the process industry have not decreased in number nor severity over the last decades even though there have been significant investments in automation. Integration between systems is argued to be a solution for improved safety rather than having disparate platforms with limited integration and connectivity. Further, *digital readiness* plays a crucial role in identifying the usage of digitalization. Lee et al. (2019) conclude that the objectives shift towards improving safety and optimizing processes depending on digital readiness.

The inevitable changes to society that digitalization entails result in challenges for mature companies to fully utilise the new technologies (Lichtblau et al., 2015). One of the problems discussed by Bower and Christensen (1995) is that companies tend to optimize and improve current processes and operations rather than develop new ways of working through new products, procedures, or manufacturing techniques. This results in companies lagging behind new companies utilizing the latest technologies (Bower & Christensen, 1995). Technology- and information-intensive firms are stated to be most vulnerable to the changes due to digitalization. However, industrial companies will be forced to undergo this transformation as well. (Downes & Nunes, 2013) This has resulted in most industries and businesses elaborate on opportunities for how digitalization can be utilised and how to manage the change (Matt et al., 2015).

For large manufacturing companies, the digital transformation faces the challenge of integrating the physical world consisting of research, development, and production with the digital world. Developing a strategy for business structure and IT has proven to be complicated. (Bilgeri et al., 2017) *Digital transformation* has become a concept to describe the change the business will need to go through to align the corporate, operational, and functional strategy. The difficulties of achieving this alignment lie in balancing the use of technology, value creation, structural changes in the company, and financial aspects. (Matt et al., 2015)

1.2 Purpose

The purpose of this master thesis is to describe and analyse production processes to identify key objectives for a company going through a digital transformation.

1.3 Delimitations

The focus of this master thesis will be to investigate a production process and assess the digital readiness within a case company. Other business areas or functions of the company will not be investigated or taken into account. Further, the digital transformation has effects both on a technical, organizational and strategic level. Since the focus will be within a production process, the focus of the assessment with digital readiness will be regarding the technical aspects rather than the organizational and strategic. A detailed discussion regarding this delimitation can be found in section *3.4.2 Application of IMPULS*.

Further, the main objectives are not to propose solutions ready for implementation. Instead, the purpose is to pinpoint interesting areas for further investigation.

1.4 Thesis Outline

Chapter 1: Introduction
The first chapter introduces the reader to the subject of the thesis. The chapter provides the background for understanding the thesis, its relevance and why the research is needed. The purpose of the thesis is presented with its delimitations.

Chapter 2: Methodology
The second chapter presents, elaborates and motivates the methodological choices the authors have taken to answer the purpose. The research approach and its process, including a flowchart of each step in the process, is shown. Further, it is presented how the data was collected and a reflection of the research credibility of the thesis is performed.

Chapter 3: Theory
The third chapter presents the theoretical framework of the thesis by presenting relevant concepts. First, a concept for understanding a company's business and its different activities is presented to illustrate where in the company this study takes place. Second, a concept for understanding how to describe and illustrate production processes is presented. The third section elaborates on

important concepts for the reader to understand to grasp the analysis of the thesis. Also, the third section is important for the understanding of the fourth section. The fourth section presents a model used for assessing the progress in a digital transformation. Lastly, the fourth section provides a summary of the theoretical framework and visualizes the interplay and connections of the different theoretical concepts used in the thesis.

Chapter 4: Empirics
The fourth chapter presents the empirical findings that were gathered during the study. First, the case company is presented. Second, the relevant production process at the case company is described with the information from observations and interviews. Third and last, the result from the performed digital readiness assessment using a questionnaire is presented.

Chapter 5: Analysis
The fifth chapter presents the analysis of the gathered data. The analysis is structured to analyse the digital readiness based on the outcome of the empiric section. The aim is to gain insights on key objectives in going through a digital transformation.

Chapter 6: Conclusions
The sixth chapter summarizes and concludes the most important findings from the analysis, with the aim of answering the purpose of the thesis.

Chapter 7: Reflections
The seventh chapter is for the authors to reflect on the thesis or express their final thoughts.

2 METHODOLOGY

The aim of this chapter is to describe the methodological choices, meaning what was done and how, to enable readers to evaluate the reliability and validity of the master thesis. The chapter includes sections describing the research purpose, research methodology, research approach, how data was collected and analysed, and lastly a discussion about the credibility of the study.

2.1 Research Purpose

A methodology is used throughout the study as guiding principles and framework for how to proceed. When choosing a methodology, it is important to assess the overall purpose of the master thesis and assure its alignment with the methodology. The overall purpose can be divided into four different categories. Descriptive, exploratory, explanatory, and problem solving. Descriptive, exploratory, and explanatory all has the purpose to investigate how something works or is carried out. The difference is that a descriptive study aims to find out and describe, an exploratory study gives in-depth knowledge and an explanatory study searches for causal links and explanations. Problem solving has the purpose of finding a solution to an already identified problem. (Höst et al., 2006)

The purpose of this master thesis is to *"...describe and analyse production processes to identify key objectives for a company going through a digital transformation"*. The purpose is both to describe production processes, and to gain in-depth knowledge of the connection between issues in production processes and the progress in going through a digital transformation for a company. This resulted in the study having both a *descriptive* and an *exploratory* purpose.

2.2 Research Methodology

According to Höst et al. (2006), the four most relevant methodologies for a master thesis are survey, case study, experiment, or action research. A survey is a compilation and description of the status on a studied object or phenomena often intended to answer a broad issue. The case study researches one or more cases to describe an object or phenomena in-depth. An experiment is based on a comparative analysis between objects to identify causal links to describe why some phenomena occur. An action research is based on surveying and documenting a study of an activity that aims to solve a problem. (Höst et al., 2006)

2.2.1 Case Study

The overall purpose of the master thesis is descriptive and exploratory as discussed earlier, therefore a case study is suitable (Höst et al., 2006). A case study explores an event or phenomena to gain in-depth and multi-faceted understanding of a complex issue in its real-life context. Furthermore, it is suitable for answering questions based on *'how', 'what'* and *'why'*. For example, '*how*' something is implemented, '*what*' gaps exist prior to an implementation and '*why*' one implementation strategy or focus is better than the other. (Crowe et al., 2011) This is closely aligned with the work of this thesis.

To gain in-depth knowledge in the production processes a case study is performed in a real-life context at the case company. It aims to eventually answer '*how*' production processes are executed and *'what'* factors that should be evaluated in operations when an organization aims to go through a digital transformation.

Case studies can be *intrinsic*, *instrumental,* or *collective. Intrinsic* case studies investigate a unique phenomenon to learn more about the phenomenon and are relatively independent of the case. *Instrumental case studies* use a particular case to gain a broader knowledge of an issue. Therefore, it is beneficial if the case is deemed to be representative for the investigated issue. *Collective case* involves multiple cases studied simultaneously to generate an even broader knowledge of an issue (Stake, 1995 look at Crowe et al., 2011). The rationale of an *instrumental case study* is used while selecting a case for the master thesis.

2.2.2 Selecting the case

For answering the purpose of the master thesis, criteria were set to find a suitable company for investigation. These criteria are summarized below:

- Manufacturing company, or similar, where production processes are critical.
- Company with complex processes and environments where the implementation of Industry 4.0 is among the hardest.
- Ongoing digital transformation.
- Production site available for visits and observations.
- Relevant development available, aiming to optimize and improve processes and operations.

LKAB, Luossavaara-Kiirunavaara AB, was found suitable for achieving these criteria. LKAB is a Swedish mining company going through an extensive digital transformation with several on-going research projects for digitalize and automate their processes. Their aim is to reach an efficient and autonomous production system that is also free from carbon-dioxide and has the highest level of safety as possible. (LKAB, 2020a) The outcome of this thesis, to evaluate LKAB's progress in going through a digital transformation, can be of use for other companies to inspire and lead the way for successful implementations.

However, LKAB is a large company and due to the time limitations, the focus area within LKAB was delimited. First, the focus of this master thesis will be within operations and within one of LKAB's main processes, namely, *mining process* in Kiruna. This since mining is the main process that enables ore to be beneficiated and then transported to customers. Additionally, mining is shown to be complex and therefore too much of a challenge to grasp the full understanding. This results in the further delimitation of focusing on the *production loading* process in mining, meaning the process where the ore is loaded onto an ore transporter before emptied in a shaft for further transportation. The process is likely to appear simple, but as the case study showed, the process contains a lot of problems that require further investigation and improvements implemented. Therefore, this master thesis focuses on the production loading process, illustrated in Figure 2. Production loading is also the process that has the most effect on the productivity in the mine, the work is to a high degree performed manually and the supporting IT-systems are insufficient. Consequently, the production loading process is suitable for the purpose of this thesis.

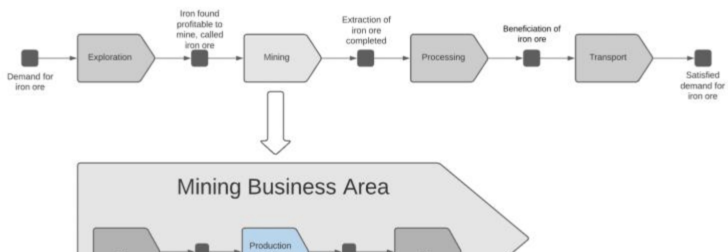

Figure 2. Illustration of where at LKAB this thesis has its focus.

2.3 Research Approach

2.3.1 Inductive, deductive or abductive

Research processes are different from each other in the way they are approached. The starting point, the aim of the research and the point in which they draw their conclusion differs. A deductive research process starts by theory studies, e.g., a literature review. From theory, some hypotheses and/or propositions are made from the researcher's logical conclusions. The empirical part of the process is then to test the conclusions only to come up with a final conclusion based on confirmation or falsification of the hypotheses and or propositions. An inductive research process follows the opposite path, meaning that the starting point is the empirical part of the process from which real-life observations are made. Eventually these observations result in final theoretical conclusions meaning that an initial theoretical study does not have to be necessary. An abductive research process can be explained as a combination of the two mentioned processes. The starting point means real-life observations that deviate from prior theoretical knowledge. This deviation initiates an iterative process where real-life observations are matched with existing theory aiming to result in conclusions that contribute to the existing theory. The conclusions can be hypotheses and or propositions that finally are tested in an empirical setting. (Kovács & Spens, 2005) In this study an *abductive approach* was taken. The process can be followed in upcoming section, 2.3.3 Research Process.

2.3.2 Qualitative or Quantitative

Quantitative research concerns relations between pre-determined variables. The study measures frequency, degree, or correlation between them (Aspers & Corte, 2019). Quantitative data can be counted or classified. For example, numbers, shares, weights, and colours. (Höst et al., 2006) . Qualitative research can be referred to as collecting and interpreting information about some phenomenon without concerns for quantities (Thomas, 2003). It is defined by Aspers and Corte (2019) as an iterative process in which improved understanding of the scientific community is achieved by making new significant distinctions resulting from getting closer to the phenomenon studied. Furthermore, the qualitative data collected is words and descriptions, nuanced and rich in detail.

Aspers and Corte (2019) emphasizes on the iterative process of qualitative research. An iterative process by comparing literature with real-life observations is encountered in this master thesis following the *abductive* research approach. In addition, Aspers and Corte (2019) explain that distinctions are made from getting close to the studied phenomena in qualitative research. The 'closeness' to the studied phenomena is a foundation for a *case study* which is the methodology used in this thesis. All in all, the master thesis takes a *qualitative research approach*.

2.3.3 Research Process

When the question from authors was handed to LKAB, issues were formulated to contribute both to the development at LKAB and also to the academia. The authors had some theoretical knowledge about the subject of the issue beforehand. However, to generate results, a systematic theory review had to be performed and matched with real-life observations.

A literature study resulted in theoretical frameworks for mapping the processes and assessing the digital readiness. These frameworks were used in empirical settings, i.e., interviews, questionnaires, and observations on-site. In addition, an archive analysis performed at LKAB to gain insights of the production processes. The research approach was iterative in the way that when the theoretical frameworks indicated that they could not contribute to conclusions they were adjusted and then tested in the empirical setting again.

When digital readiness was assessed and propositions on how to move forward had been generated from the analytic section, a conclusion was made with proposals and thoughts of the work. The research process is illustrated in Figure 3.

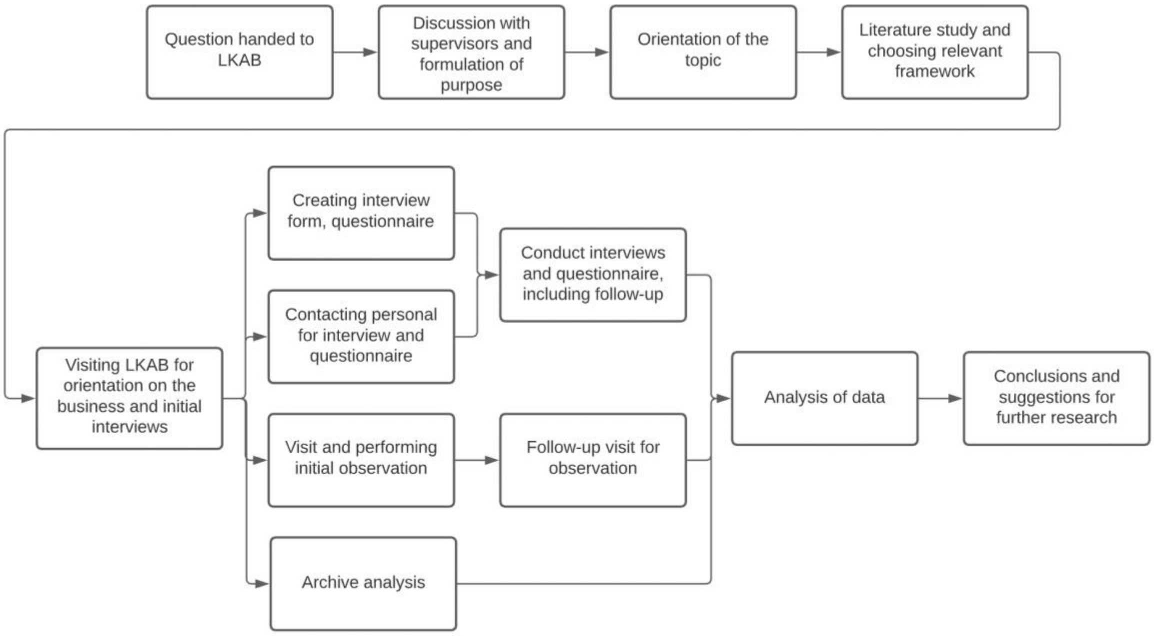

Figure 3. Illustration of the research process followed throughout the thesis.

2.4 Data Collection

The activity to collect the data that is used for analysing and answering the purpose of a study can be performed in various ways. Questionnaires, interviews, observations, measurements and written documents cover the main data collection methods used. The methods serve different purposes and can be used individually or as complementary methods to reach a conclusion. (Höst et al., 2006) The data collection methods used in this master thesis are presented below.

2.4.1 Interviews

Interviews were conducted to get an extensive understanding of how the processes in operations are performed and how they can be improved. The initial focus of the interviews was to get an understanding of how activities are realized. As the processes became clear, interviews got more specific to provide a more thorough understanding of the daily work and opportunities investigated to be implemented. (Höst et al., 2006)

Interviews can be structured in three different ways, *structured interview*, *semi-structured interview* and *unstructured interview*.

- A structured interview has fixed questions and specific answers, as in a questionnaire. The aim of a structured interview is to understand the relationship and connection between different concepts.

- An unstructured interview uses a general interview guide with open-ended questions. The aim is to explore the individual's experience and expertise of a phenomenon.
- A semi structured interview is a combination of structured and unstructured interview. (Höst et al., 2006)

Unstructured interviews were conducted for this study. The first interviews were performed to get the basic understanding of LKAB's processes in a company-wide perspective, before getting more and more detailed, ending up with the activities performed in loading. As the procedures became clearer, unstructured interviews with relevant people were conducted to get perspectives and insights from a wide range of experience and expertise.

2.4.1.1 Interviews for initial understanding

Initial unstructured interviews without prepared questions were held with supervisors, Mine Planner Strategist and Mine Planning Engineer, to get the general understanding of LKAB's business idea. This general understanding ranged from exploration to find minerals in the bedrock to the transportation to customers. As the business idea became clearer, and the main processes were understood, the mining processes were studied for the understanding of how the ore was mined and transferred to the surface. As the interviews proceeded, it became clear that the mining process was too big of a challenge to cover due to time limitations. Loading process was described as having the most effect on productivity and currently facing a number of challenges, e.g., within digitalisation and automation. Therefore, the loading process, where the ore is loaded onto a LHD to be transported the ore pass before further transportation, was subject for a comprehensive understanding.

2.4.1.2 Interviews with key figures for deepen understanding

These interviews aimed to provide a deepened understanding of different aspects of the loading process as well as verifying the mapped process and our understanding of how the work is realized. Some initial questions were prepared for these interviews. The questions prepared are to be found in Appendix C.

Interview with IT

Interview conducted for the insights of current way of working along with current projects to improve the processes and procedures performed in loading. Since improvements in digitalization is one of the main areas of development in most companies today, as well as in LKAB, the interview resulted in valuable information for understanding data collection, IT-systems and connected systems. The interview was conducted with a *Cybersecurity and Enterprise Strategist* at LKAB with long experience implementing interoperable IT-systems and automation.

Interview with Automation

Automation is another of the main development areas in progress at LKAB with the aim of improving safety and productivity in the mine. The interview provided valuable insights for the way automation is used today and to which extent. Further, research and development were discussed and provide information of what improvement automation entails for the future. The interview was conducted with a *Research Engineer* at LKAB with long experience in working with automation and logistics.

Interviews with Mine Planning

The interviews with mine planning were conducted to analyse the flow of work, or rather the flow of information, throughout the loading process. A major area of early digitalization projects is to digitalize the flow of work to speed up lead-times and reduce idle time. For this, two interviews were conducted. The first with *Mine Planning and Layout Specialist*, and the other one with *Mine Planning Engineer*. Questions covered subjects such as planning, decision support and production stoppage.

Interview with Production managers
To get insights of the people working closer to the actual loading process, *two Production Managers* were interviewed. Useful for verifying the understanding of the process and problems faced in daily work. Further, the production managers could give their perspective on the change, improvement areas and employees thoughts of the reformation taking place. Interview covered discussion of the daily activities in loading, current procedures and problems linked to these.

Interview with Operator
In addition to the production managers, one *Operator* was interviewed to get the perspective of the workers performing the actual loading process. The interview aimed to verify our understanding of the performance of the process. Additionally, the interview aimed to get the insights of operators' everyday work and their struggles. Focus of the interview was both to clarify the current working environment, and also to elaborate on the future of the loading process and what opportunities the operators see.

2.4.2 Observations

Observations are suitable for studying a phenomenon or a process to understand what is happening, hence useful in a wide range of questions. Observations are performed by following the process and note the impressions along the observations. Technical tools can be used. One differs observation methods with two factors, whether the observer is actively involved in the phenomenon studied or not and whether the ones observed know that they are observed or not. For the observations executed, the method of the *participating observer* was used. Meaning that the observers were not actively included in the work and that the observers were known. (Höst et al., 2006)

This approach was used because of the safety concerns limiting observers to be actively involved in the work. The benefit of being actively involved in the processes are limited since the procedure of the processes were to be studied and remain the same. Although, a hands-on experience could have benefited the understanding of why certain activities are performed the way they are. Further, the observers were known due to the fact that the purpose was to understand how the process was performed and therefore answers and explanations from workers were favourable. (Höst et al., 2006)

Observations were conducted for the understanding of how the production process was realized. The observations made it possible to verify the idea of how activities were performed and compare it to the initial flowchart created with the basis of the initial interviews. Further, the observations were conducted for the basic understanding of the mine. During the observations, the relevant activities related to the loading process performed in the mine were shown. Pictures were taken and are included in the thesis. Further, conversations with personnel working in the activities contributed with knowledge and insights.

2.4.3 Questionnaire

The questionnaire is basically a survey. However, to minimize the confusion of a survey as a research methodology discussed in section 2.2 Research Methodology, it will be referred to as a *questionnaire*. A questionnaire has fixed questions and predefined answers. It can be used to gain information and insights on various topics. There are different ways to conduct a questionnaire.

In this thesis, a computer questionnaire is used, which means that a link is sent out via email to relevant respondents. (Höst et al., 2006) This is found in Appendix B.

The aim of the questionnaire was to collect information of the company's, LKAB's, progress in going through a digital transformation from the perspective of production loading within mining. However, this delimitation in perspective was not clarified to the respondents since the authors thought it was clear from the interviews. Which was shown afterwards, it was not. Analysis was made to mitigate the effects of this incident by trying to understand through what perspective the respondent thought of while answering each question. This analysis was enabled due to the comments left by the respondents.

The questions were qualitative and focused on different aspects of the digital transformation. This was thought to provide insights of key objectives for how to move forward. The result was also used for assessing LKAB's level of digital readiness. In this case, the questionnaire was sent to the same people who were interviewed. This enabled an analysis to evaluate the connection between the information collected from the interview and the answers in the questionnaire. An analysis was done to verify that the assessed digital readiness level, and its model used, is appropriate and applicable.

The questionnaire was sent via email. In the case of the interviewee not answering the questionnaire, a reminder email was sent and thereafter the interviewee was called and requested to fill the questionnaire. Five interviewees out of six, did fulfil the request to answer the questionnaire.

2.4.4 Written documents and material

A literature study was performed. The literature study gave the authors the possibility to gain deeper knowledge within the field and investigate theories and frameworks to both see the study in a larger perspective as well as go into details on certain areas. The literature study was performed in the beginning of the thesis to gain information on the theoretical framework to use.

The literature study was mainly performed using Google Scholar, LUBSearch and LIBRIS. Several types of literature were studied, e.g., books, journals, articles and conference papers. The findings were organised and saved for later use with EndNote. Search strings used for the literature study are found in Appendix E.

In addition to the data collected through the case study, i.e., interviews, observations and questionnaire, the authors performed an archive analysis at LKAB. Multiple written documents, material and webpages concerning LKAB were read and used for understanding and supporting the analysis of the thesis. These were internal company documents, e.g., annual reports, company brochures, educational material, LKAB's webpage, previous master and doctoral thesis within the subject.

2.5 Credibility of the study

2.5.1 Reliability

The reliability of a research and its methodology reflects on the trustworthiness of the data collection and its analysis, in regard to random variations. Meaning, the extent the results can be reproduced when the research is repeated under the same conditions. Reliability is assessed by checking consistency of results and answers. To achieve high reliability, a thorough, accurate and detailed data collection and analysis should be performed. It is also important to clearly present how the research was conducted to enable the reader to make a judgement of the actual research realisation. (Höst et al., 2006)

To improve the reliability of this thesis, several actions were taken. Multiple sources were scanned through databases to gain insights of the numerous theoretical concepts available. From these, a few concepts were selected to be adequate for the purpose of this thesis. The concepts used were well-founded and used in similar applications before.

Further, the outcome of the different activities used for collecting data was verified retrospectively. E.g., the description of production processes was verified with multiple workers from different divisions, follow-up on interviews was made to secure our interpretations being accurate.

For the reader to understand the research process, a detailed illustration of the activities performed is provided and the interview questions and questionnaire is included in the appendices.

2.5.2 Validity

The validity of a research is the extent the results measures what is supposed to be measured. To improve the validity of a study, one can study the same thing from different perspectives, called triangulation. (Höst et al., 2006)

The validity of this thesis is considered high. This is due to the multiple data collection activities used. Interviews were complemented by observations to validate the interpretations. Hence, studying the same thing from different perspectives, i.e., triangulation.

Further, the assessment of the digital readiness to find the key objectives in going through a digital transformation were performed in two separate approaches, although using the same model. The two different approaches were to use a questionnaire or to analyse the result from the interviews and observations. This is another example of triangulation.

Lastly, to validate the outcome of the thesis regarding the digital readiness, data on previous assessments of digital readiness were used to benchmark this thesis result on previous. However, a potential drawback on the validity was found during the analysis of the questionnaire due to the exclusion of definitions and concepts. Although, the reduction in validity is for the digital readiness model, called IMPULS, and not the thesis in itself.

3 THEORY

This chapter presents the theoretical framework of the thesis and its relevant theoretical concepts. The chapter is divided into five main sections:

The first section provides theories and concepts for understanding the value system and value chain of a company. The aim is to provide theory related to answering the question of where in a company this study has its focus, i.e., the firm's value chain and within operations.

The second section defines the concept of processes and provides theoretical methods for mapping processes. The second section aims to provide theories for describing how processes are performed. This to gain insights of operations later analysed for identifying key objectives in going through a digital transformation.

The third section aims to provide knowledge and insights of digital technologies for the reader to understand the concepts of digital readiness and digital transformation.

The fourth section provides a theoretical model to support the authors in identifying key objectives in going through a digital transformation.

The fifth section provides a summary of the theoretical framework and visualizes the interplay and connections of different theoretical concepts used in this master thesis.

3.1 Value system and defining the focus of this report

Competitive advantage for businesses can best be understood when looking at the company as a whole (Ljungberg & Larsson, 2012, p. 183; Porter, 1985). A firm performs many different activities such as producing, marketing, delivering and supporting its product. In addition, a firm is embedded in a complex system with supplier-, channel- and buyer value chains. All of these have their own internal activities. Porter (1985) illustrates the relations between firms with a *value system*, see Figure 4. To gain competitive advantage, a company needs to understand its own value chain and how it fits into the value system. (Porter, 1985)

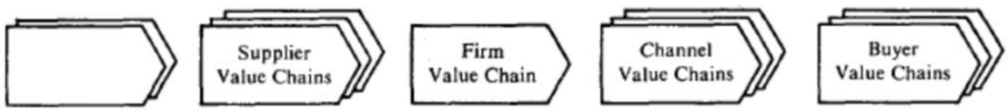

Figure 4. The Value System. (Porter, 1985)

A firm's activities can be illustrated with *the generic value chain*, see Figure 5, visualizing how activities in a firm interact and need to be understood to fully grasp the potential of creating value for customers. The performance of each activity will reflect the costs and the value created for customers. Hence, each activity is important in order to differentiate the company. For larger companies or corporate groups, the generic value chain becomes too complex due to cross-connections between activities to create value. Therefore, the appropriate level for the generic value chain is a particular industry or business unit. (Porter, 1985)

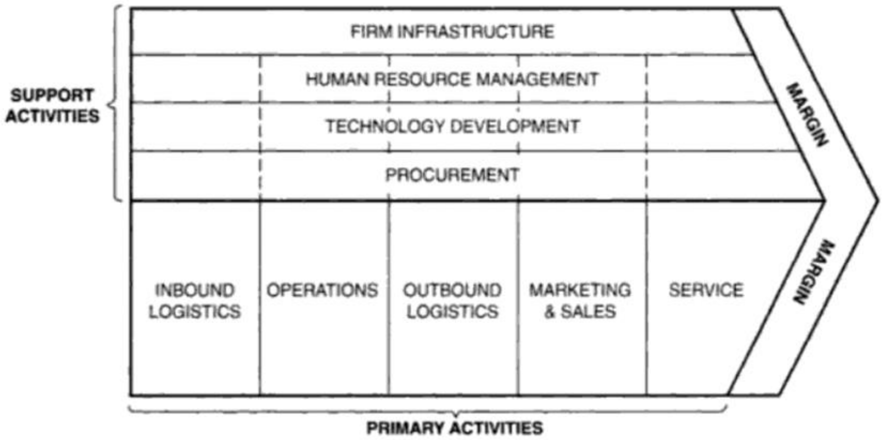

Figure 5. The Generic Value Chain. (Porter, 1985)

The generic value chain consists of primary activities and support activities. The primary activities are involved in the physical transformation of the product and its sales and transfer. The primary activities are classified into five categories:

- Inbound logistics – activities relating to receiving and storing inputs to the product e.g., material handling, warehousing, inventory control and returns to suppliers.
- Operations - activities relating to transforming inputs into the final product form, e.g., machining, packaging, assembly, maintenance and facility operations.
- Outbound logistics – activities relating to collecting, storing and physically distributing the product to buyers, e.g., finished goods warehousing, material handling and delivery vehicle operation.
- Marketing & Sales – activities related to the strategy enabling the selling of the product through e.g., advertising, sales force, channel relation and pricing.
- Service – activities related to maintenance of the final product, e.g., installation, repair, training and product adjustment. (Porter, 1985)

The support activities help the primary activities to be performed more efficiently. If the support activities are to be improved, it benefits the primary activities in one way or the other. The support activities are classified into firm infrastructure, human resource management, technology development and procurement. (Porter, 1985)

3.1.1 Operations

This section takes base in the value system described above and aims to set a frame of reference in regard to 'where' the focus of this master thesis lies by identifying the components of the value system that are included in the transformation of digitalized processes in production.

The production of a product relates to the actual transformation of a product, using inputs such as raw material and turning it into the final product. In Porter (1985) generic value chain, this is performed in the operations, which will be the focus of this master thesis. See Figure 6.

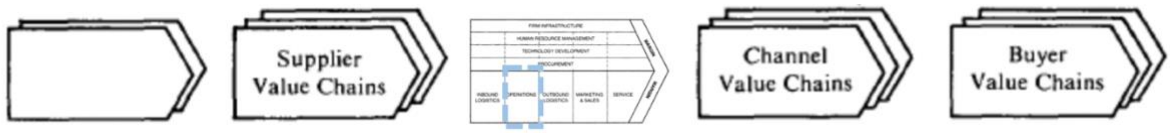

Figure 6. Showing the value system and the value chain with the box focused on the centre of this master thesis.

3.2 Processes Management used to 'describe'

Process management, the mindset of seeing the business as processes, is not a new concept. The ideas were popularized during the 1970s with methodologies such as just-in-time and lean production (Schonberger, 1986). During the 1990s business process re-engineering (BPR) progressed by Hammer and Champy (1993). Even though the concepts are widely used, there is no single definition of *process*, although most of them are similar (Palmberg, 2009, p. 14). Hammer and Champy (1993) defines processes as activities that take one or more inputs and create an output that is of value to the customer. Their definition is simple to understand, but also considered to be incomplete (Weske, 2007). Weske (2007) reviews numerous amounts of definitions and suggests the explanation "*A business process consists of a set of activities that are performed in coordination in an organizational and technical environment. These activities jointly realize a business goal. Each business process is enacted by a single organization, but it may interact with business processes performed by other organizations.*" Palmberg (2009) has performed a literature study and after comparing different definitions, the net process definition is condensed to *"a horizontal sequence of activities that transforms an input (need) to an output (result) to meet the needs of customers or stakeholders"*. The various definitions are similar. Hence, there is no real point in deciding any definition for this study. Instead, the definitions cited are thought to be used to complete each other. A final notation is that the word *process* is used interchangeably with *business process* in academia, in this master thesis, process will be preferred.

Processes can be related in long and complex sequences. A common problem related to process mapping is to generate a far more detailed process map than necessary (Ljungberg & Larsson, 2012, p. 204). Hence, a hierarchy of processes is useful. Four categories often used are *process, sub-process*, *activities* and *tasks* (Palmberg, 2009). Ljungberg and Larsson (2012) have a similar categorization consisting of *process*, *sub-process* and *activities*. The process is broken down into sub-processes, which in turn is broken down into activities, see Figure 7. The levels are relevant for different applications. Process view is necessary to understand the holistic perspective of the value creation. Sub-processes and activities are relevant for detailed representation of the process when implementing and evaluating improvements e.g., IT-solutions. (Ljungberg & Larsson, 2012, pp. 190, 204)

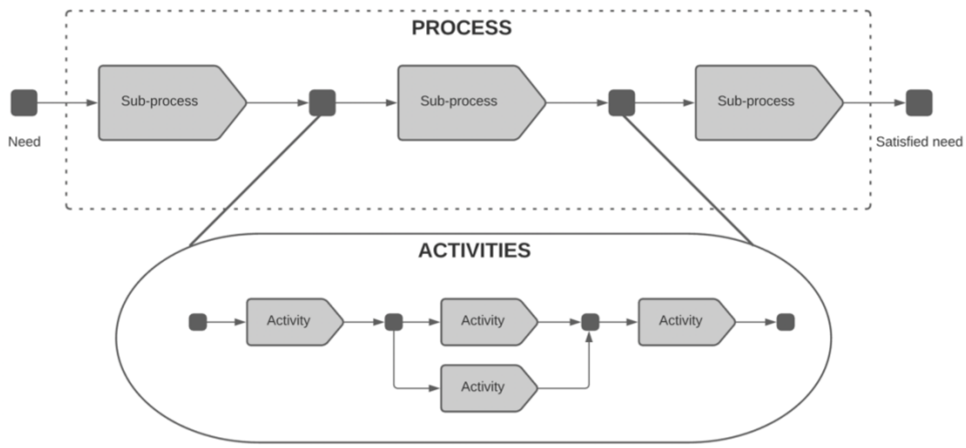

Figure 7. Illustration of hierarchy of processes according to Ljungberg and Larsson (2012).

3.2.1 Process Mapping using value-based process modelling

The purpose of mapping processes is to comprehensively present and illustrate the flow of work to understand how processes and activities interact for value creation. The aim is to reduce functional thinking to gain insights for potential improvements in e.g., efficiency, quality, safety and communication. Process mapping is stated to be an enabler for further improvements. However, it is important to understand that the actual mapping itself does not result in any improvements. (Ljungberg & Larsson, 2012, pp. 187-188, 191)

Numerous models for process mapping are available with a variety of complexity and focus depending on the purpose of the process mapping. Ljungberg and Larsson (2012, p. 197) presents a more flexible model called value-based process modelling (VPM), useful for most applications, that combines the major characteristics of several process models, see Figure 8. VPM focuses on comprehensibility and uses the most important symbols to utilise readability and still enable in depth analysis. (Ljungberg & Larsson, 2012)

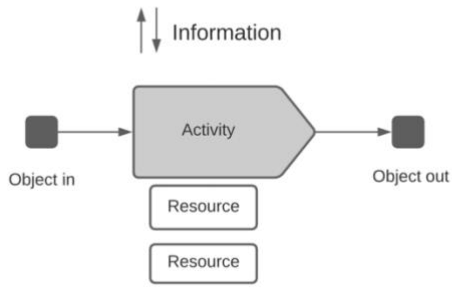

Figure 8. The essential components in value-based process modelling (VPM). (Ljungberg & Larsson, 2012)

The essentials of VPM are:

- Object in – Starts or triggers the process, sub-process or activity.
- Activity – The actual work or tasks performed to refine an object in.
- Information – Supports or controls the process, sub-process or activity.
- Resources – What is needed for the process, sub-process or activity to be performed. E.g., personnel, equipment, facilities etc.
- Object out – What is refined by the process, sub-process or activity. Acts as input to the next step in the process. (Ljungberg & Larsson, 2012, pp. 206-207)

3.3 Digital transformation & Industry 4.0

Numerous definitions of digital transformation exist depending on the context. From an industry perspective, digital transformation can be described as the transformation and ongoing digital evolution of a company's organizational structure, business model, products and processes to create value for the company using digital technologies. (Hess et al., 2016; Mazzone, 2014; Stark, 2020; Verhoef et al., 2019)

"Industry 4.0" can be presented as the digital transformation of manufacturing and production industries. (i-SCOOP, n.d.) Industry 4.0 has an important role for organizations in producing companies in order to adapt their strategies to leverage on digitalization enabled by the many emerging digital technologies. The adaption aims to increase resource efficiency as well as productivity to further increase competitiveness of companies. (Onar & Ustundag, 2018) Furthermore, adaptation to Industry 4.0 offers increased economic benefits, smart production and reduction in energy consumption (Li et al., 2017). The term "Industry 4.0" is originally from Germany, *Industrie 4.0*, where it was a strategic initiative by the government to transform industrial manufacturing through digitalization and exploitation of the enabling digital technologies (Dalenogare et al., 2018; Rojko, 2017).

3.3.1 Enabling technologies

The definition of Industry 4.0 by Ardito et al. (2019) has a notable emphasis on the technologies that can be used to underline their role in Industry 4.0. "*The main idea underlying the industry 4.0 is running businesses by adopting digital technologies that can help firms to create connections between their machinery, supply systems, production facilities, final products, and customers in order to gather and share real-time market and operational information"*.

The definitions of digital transformation and explanations of Industry 4.0, accentuates the relevance of the digital technologies. They can be explained as technologies providing intelligence, connection, communication, and automation between and within companies. (Li et al., 2020; Núñez-Merino et al., 2020)

Raut et al. (2020) performs a systematic literature review across multiple databases to identify the key enabling technologies towards Industry 4.0 in the manufacturing and supply chain management context. The review resulted in five key enabling technologies, four of them are presented in Figure 9. Since the fifth, blockchain technology, is still an evolving technology, Raut et al. (2020) found very few reputed, peer-reviewed journals covering the subject. Therefore, it is not further explained in this master thesis. Leaving Radio Frequency Identification (RFID), Internet of Things (IoT), Cloud Computing, Big Data Analytics to be explained. Beyond the literature review made by Raut et al. (2020), the four selected technologies for further explanation in this master thesis have proven to be prevalent in the literature and often referred to by other authors in the context of enabling technologies for Industry 4.0. (Ardolino et al., 2018; Dalenogare et al., 2018; Li et al., 2020; Núñez-Merino et al., 2020; Wang et al., 2016)

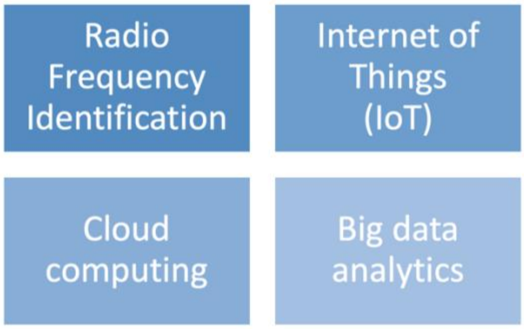

Figure 9. Showing the supportive techniques of major importance according to Raut et al. (2020).

RFID is an information and communication technology (ICT) that uses tags on physical objects to identify, track and manage the objects automatically (Ting et al., 2011). The hardware systems main components are tags, readers and some middleware, usually antennas. The tags are equipped with physical objects. The tags are stored with information about the object and/or its surroundings. Readers capture the information from the tags and the middleware acts as a link between the hardware and software systems. When the data is collected and processed into the software system it can be utilised in various ways. One of many applications is tracking and tracing a product throughout the manufacturing and supply chain. (Raut et al., 2020)

IoT is described as "*A new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other*" (Lee & Lee, 2015) The elements of the network are physical objects that are connected to the internet. IoT enables the physical objects to communicate and thereby share information to coordinate decisions (Al-Fuqaha et al., 2015). Boyes et al. (2018) suggests the more extensive explanation of industrial IoT as a network consisting of smart objects, information technologies and cloud computing platforms that in turn enables functions as real-time and autonomous collection, analysis, and communications to exchange product and service information. The use of these technologies and their functions is aimed to optimize overall production value in an industrial environment, for example, improved productivity, reduced labour costs and reduced energy consumption. (Boyes et al., 2018)

Cloud Computing is a computing model providing resources that can be accessed through the web. Avram (2014) investigates several definitions of Cloud Computing. The definition that was perceived most explicable was the one by Mell and Grance (2011): "*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.*" One of the many benefits of cloud computing is the applications and services that can be used from the cloud platform. Real-time responding mobile applications respond to information from human and non-human devices e.g., humidity sensors in a shipping container. Furthermore, by analysing large volumes of data that is enabled by large processing power and business analytics through cloud computing, companies can understand e.g., buying habits and complex supply chains. (Marston et al., 2011)

Big Data Analytics needs to be managed due to the many connected devices of the Internet of Things that generates big datasets for cloud computing. The big datasets are characterized by its growing volume, velocity and variety and are referred to as "*Big Data*". (Elgendy & Elragal, 2014; Jeble et al., 2016) Data analytics implies mining, extraction, and interpretation of information from big datasets to generate insights and understand meaningful patterns with potential to serve as a basis for decision making (Ojokoh et al., 2020). Jeble et al. (2016) differs between three different categories when big data analytics is useful. *Descriptive analytics* captures and analyses data to gain insights and is explanatory in its nature. *Predictive analytics* develops models from input data to generate patterns and predict future outcomes. Lastly, *prescriptive analytics* develops a model for decision making to optimize outcomes. To get a sense of what technologies are relevant to big data analytics today, Davenport (2018) discusses the development of "analytical activities" over the lifespan of the concept. The most recent eras have implied traditional industries to embark in big data analytics. Before that, it was mainly used by online firms. Consequently, analytical activities have been *industrialized*. This has been enabled partly by the integration of AI to big data analytics. AI techniques such as machine- and deep learning will pave the way for the future of big data analytics due to their unique capability of learning from data input and generate new rules for future business analytics (Maryville University, n.d.)

3.4 Industry 4.0 Readiness Model

It is important to understand what state in the transformation a company is in and what path that must be pursued to achieve the full potential of Industry 4.0. An Industry 4.0 readiness model is a classification framework that can support understanding the potential gap between the current level and desired level of Industry 4.0 implementation for an organization. (Schumacher et al., 2016)

Maturity and readiness models are often labelled synonymously in the literature, in this study, readiness is preferred. Readiness models aim to apprehend a starting point for further development. (Schumacher et al., 2016) There exist many different models with similar characteristics. Some of these are summarized by Akdil et al. (2018). This master thesis will proceed with further studies on the Industry 4.0 readiness model, *IMPULS,* by Lichtblau et al. (2015). IMPULS is chosen due to being comprehensible and used in relevant studies for the purpose of this master thesis.

3.4.1 Description of the IMPULS model

In this master thesis, the Industry 4.0 readiness model called *IMPULS* will be used. IMPULS is developed to measure "*the degree of sophistication on the road to Industrie 4.0- of companies in Germany's mechanical engineering industry*". It is stated that in order to stay competitive, companies must assess where they are in the digital transformation process as well as assessing if they are exploiting the full potential of Industry 4.0. IMPULS is thought to enable this assessment. (Lichtblau et al., 2015)

3.4.1.1 Areas evaluated to determine readiness

The progress of achieving digital transformation is measured with six *dimensions,* shown in Figure 10. Each dimension represents an area important for the digital transformation and Industry 4.0. Each dimension is further divided into *fields* related to the dimension. Each field has appropriate indicators and criteria to be evaluated to measure readiness within the specific dimension. (Lichtblau et al., 2015)

Figure 10. Illustration of dimensions and fields in IMPULS. (Lichtblau et al., 2015)

Strategy and organization
Dimension used for measure and to understand the readiness of the managers, stakeholders and the business strategy. Fields reviewed for evaluation are implementation status of digital strategy, investment activity related to Industry 4.0 and the use of technology and innovation management. The main obstacle for achieving a higher level is lack of a comprehensive digital strategy and progress indicators for the Industry 4.0 implementation. (Lichtblau et al., 2015)

Smart factory
Interconnected factory with communicating production- and IT systems such as MES (Manufacturing execution system), ERP (Enterprise resource planning) and smart products. A key enabler for a smart factory is the placement of sensor technology to collect and manage relevant data for optimization and continuous improvement. Fields reviewed for evaluation are digital modelling, equipment infrastructure, data usage and IT systems. The advancement in smart factory level's requires heavy investments in production. (Lichtblau et al., 2015)

Smart operations
Smart operations relate to the importance of integration of all components and systems of the value chain, both internal and external. Establish a cross-enterprise planning and control to utilise productivity, quality and flexibility. Key enabler for cross-enterprise information sharing to be efficient is the usage of sensor technology to collect the right data to be shared, and that the collected data has high resolution to provide relevant insights. Fields reviewed for evaluation are information sharing, cloud usage, IT security and autonomous processes. (Lichtblau et al., 2015)

Smart products
Smart products are stated to be the foundation for the smart factory, smart operations and data-driven services due to these dimensions rely on availability of comprehensive information and data. Smart products are uniquely identifiable and collect data from the environment, sensors and various add-on functionalities. The products themselves communicate with machines for the next step in production or sending data for analysis, therefore it needs to have the information about itself. Fields reviewed for evaluation are ICT add-on functionalities and data analytics in usage phase. (Lichtblau et al., 2015)

Data-driven services
The focus towards data-driven services can be expressed as *"companies evolving from selling products to providing solutions"*. For companies, this results in the need of a fundamental rethinking of existing business models to utilise new business models with the focus of adding value through data collection and analysis. Examples can be combining products and services, such as maintenance, for increased value to the customer. Fields reviewed for evaluation are availability of data-driven services, share of revenues derived from data-driven services and share of data used. Data-driven services is the dimension with the lowest readiness level in study performed by the model developers. (Lichtblau et al., 2015)

Employees
Employees provide the company with expertise and knowledge. The swift in competence needed makes it critical for companies to ensure skills availability in relevant areas through training and education. Fields reviewed for evaluation are employee skill set and company's effort for skill acquisition. (Lichtblau et al., 2015)

3.4.1.2 Evaluation of readiness in certain areas, called *dimensions*
Companies are categorized into levels of readiness reaching 0-5 within each of the six dimensions mentioned earlier. These levels are labelled outsider (level 0), beginner (level 1), intermediate (level

2), experienced (level 3), expert (level 4), and top performer (level 5). The criteria used for evaluation of each dimension and its fields are shown in the following figures. (Lichtblau et al., 2015) Also, a more explicit description of each field is found in Appendix A.

Evaluation of the dimension Strategy and Organization

The criteria to evaluate and position companies at different levels within *strategy and organization* is shown in Figure 11.

Strategy and organization: Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Degree of strategy	Industry 4.0 is not part of the strategic progress	Industry 4.0 is an issue at the departmental level but is not integrated into the strategy	Industry 4.0 is part of the strategic process, and a strategy is being developed	An Industry 4.0 strategy has been defined	An Industry 4.0 strategy is in implementation	An Industry 4.0 strategy has been implemented enterprise-wide
Definition of indicators	No indicators exist to determine the status of Industry 4.0 implementation	No indicators exist to determine the status of Industry 4.0 implementation	A system of indicators is in place that gives a sense of the status of implementation	A system of indicators is in place that gives a sense of the status of implementation	A system of indicators is in place that gives a sense of the status of implementation	A system of indicators is in place and integrated into the strategic process
Investments	No Industry 4.0 investments	Initial Industry 4.0 investments in one area	Low level of Industry 4.0 investments	Industry 4.0 investments in a few areas	Industry 4.0 investments in several areas	Industry 4.0 investments enterprise-wide
Innovation management	No innovation management	No innovation management	No innovation management	Innovation management in isolated areas	Innovation management implemented in several departments	Uniform, interdepartmental innovation management has been established

Figure 11. Showing criteria used for evaluation of strategy and organization. (Lichtblau et al., 2015)

Evaluation of the dimension Smart Factory

The criteria to evaluate and position companies at different levels within *smart factory* is shown in Figure 12.

Smart factory: Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Equipment infrastructure (current)	Machine and system infrastructure cannot be controlled through IT, no integration (M2M)	Some machines can be controlled through IT, are interoperable, or have M2M capability	Machine and system infrastructure can be controlled to some extent through IT and is integrated	Machine and system infrastructure can be controlled through IT and is partially integrated	Machinery can be controlled completely thorough IT, is partially integrated (M2M) or interoperable	Machines and systems can be controlled almost completely through IT and are fully integrated (M2M).
Equipment infrastructure (target)	Machines and systems cannot be upgraded	Future requirements for machines and systems are relevant	Some machines and systems can be upgraded	All machines and systems can be upgraded	Machines already meet some of the requirements or can be upgraded	Machines and systems already meet all future requirements
Digital modeling	No digital modeling	No digital modeling	Some digital modeling	Some digital modeling	Some digital modeling	Complete digital modeling possible
Data collection	No digital is collected	No digital is collected	Data is collected but for the most part manually	The relevant data is collected digitally in certain areas	Comprehensive digital data collection in multiple areas	Comprehensive automated, digital data collection in all areas
Data usage	No data available for further use	No data available for further use	Data is used for selected purposes (greater transparency, etc.)	Some data used top optimize processes (predictive maintenance, etc.	Data used in several areas for optimization	Data used for comprehensive process optimization
IT systems	No support through IT systems	Main business proves supported by IT systems	Some areas of the business are supported by IT systems and integrated	Some areas of the business are supported by IT systems and integrated with one another	Complete It support of processes, full integration	It systems support all company processes and are integrated

Figure 12. Showing criteria used for evaluation of smart factory. (Lichtblau et al., 2015)

Evaluation of the dimension Smart Operations

The criteria to evaluate and position companies at different levels within *smart operations* is shown in Figure 13.

Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Smart operations: System-integrated information sharing)	No system-integrated information sharing	Beginnings of in-company, system-integrated information sharing	In-company information sharing partially system-integrated	Some in-company and beginnings of external system-integrated information sharing	Predominantly in-company and partially external system-integrated information sharing	Comprehensive in-company and partially external system-integrated information sharing
Autonomously guided workpieces	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise
Self-reacting processes	Self-reacting processes not in use	Self-reacting processes not in use	Self-reacting processes not in use	Self-reacting processes not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise
IT security	No IT security solutions in development or implemented	Initial IT security solutions planned	Multiple IT security solutions are planned or initial solutions are in development	IT security solutions have been partially implemented	Comprehensive IT security solutions have been implemented, existing gaps are being closed	IT security solutions have been implemented for all relevant areas
Cloud usage	Cloud solutions not in use	Cloud solutions not in use	Cloud solutions not in use	Initial solutions planned for cloud-based software, data storage, and data analysis	Initial solutions implemented	Multiple solutions implemented

Figure 13. Showing criteria used for evaluation of smart operations. (Lichtblau et al., 2015)

Evaluation of the dimension Smart products

The criteria to evaluate and position companies at different levels within *smart products* is shown in Figure 14.

Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Smart products: ICT add-on functionalities	No add-on functionalities	Products show first signs of add-on functionalities	Products feature initial add-on functionalities	Products feature multiple, interrelated add-on functionalities	Products feature add-on functionalities in different areas	Products feature extensive add-on functionalities
Use of data	No data collected	No data collected	Data collected but not analyzed/used	Data analyzed/used	Data analyzed/used	Data analyzed/used

Figure 14. Showing criteria used for evaluation of smart products. (Lichtblau et al., 2015)

Evaluation of the dimension Data-driven services
The criteria to evaluate and position companies at different levels within *data-driven services* is shown in Figure 15.

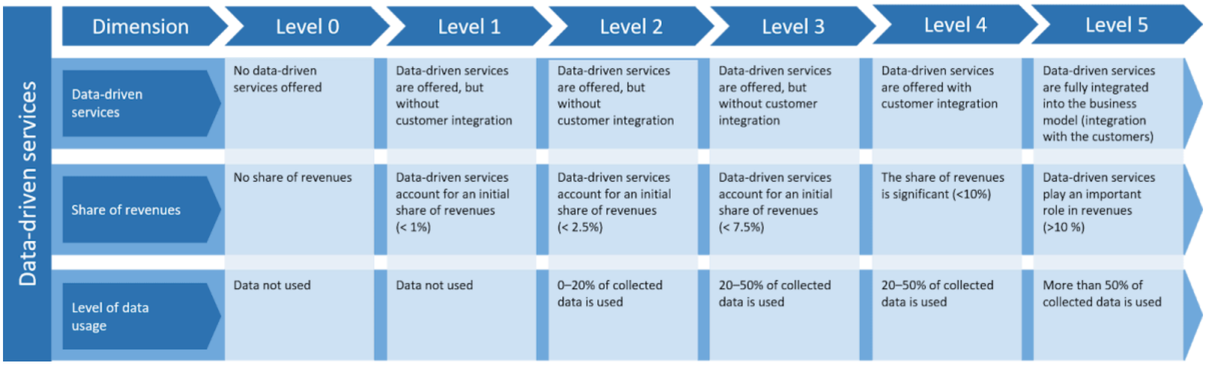

Figure 15. Showing criteria used for evaluation of data-driven services. (Lichtblau et al., 2015)

Evaluation of the dimension Employees
The criteria to evaluate and position companies at different levels within *employees* is shown in Figure 16.

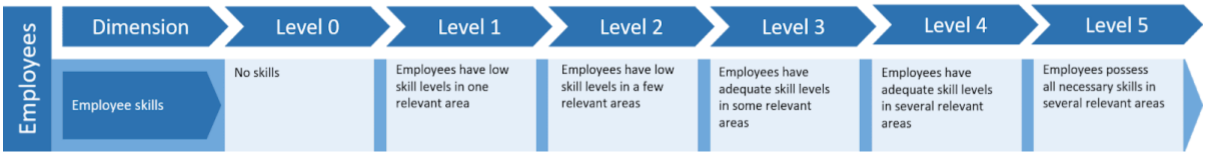

Figure 16. Showing criteria used for evaluation of employees. (Lichtblau et al., 2015)

3.4.1.3 Assessment of company's readiness

To grasp a company's readiness for Industry 4.0, the six dimensions are rated individually and weighted to achieve an overall score for the company's readiness. The weighted systems work such as each dimension's readiness level is multiplied with its weight and then summarized to get the company's readiness. Weights are as follows, strategy and organisation 0.25, smart factory 0.14, smart operations 0.10, data-driven services 0.14, smart products 0.19 and employees 0.18. A dimension's level is decided by the field with the lowest readiness level. (Lichtblau et al., 2015)

Levels are labelled the same as for dimensions, shown in Figure 17. However, the levels are further divided into newcomers (level 0-1), learners (level 2) and leaders (level 3-5). For assessing a result to a certain digital readiness level, the weighted sum is always rounded down. Meaning, to achieve level 3 and be categorized as a leader, the weighted sum must equal 3 or above. (Lichtblau et al., 2015)

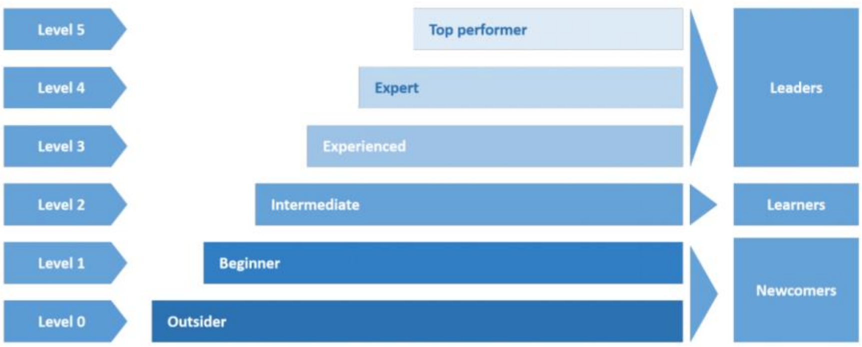

Figure 17. Showing readiness levels and their division in newcomers, learners and leaders.

A study performed in Germany used IMPULS for classification of companies. Resulted in 5.6 percent of the companies being leaders in the digital transformation and Industry 4.0. 17.9 percent considered learners, taking their first steps for the transformation to happen. Lastly, 76.5 percent of the studied companies were considered to be newcomers and had no systematic approach for transforming their industry. Even though this result is only applicable for German industry, it provides an interesting insight of the distribution of companies in the model. (Lichtblau et al., 2015)

3.4.2 Application of IMPULS

IMPULS aims to cover the Industry 4.0 readiness of an entire organization. The purpose of this master thesis is to identify key objectives for a company going through a digital transformation by focusing on a company's production processes. Consequently, four out of six dimensions are selected from IMPULS for the purpose of facilitating a more precise analysis on the relation between the readiness of relevant dimensions and production processes in operations.

3.4.2.1 The included dimensions

A description and analysis of a company's processes in production followed by an assessment of Industry 4.0 readiness of the dimensions *smart factory, smart operations, smart products*, and *employees* is performed in this master thesis. The chosen dimensions are reasoned to encourage evaluation of the opportunities to fully utilise digitalization in production processes.

The **smart factory** is a central role for the Industry 4.0 readiness. The dimension is based on production systems in the factory that communicates with employees, smart products and IT systems, i.e., smart operations. This integration enables efficient information delivery and resource use, making the factory intelligent and interconnected. The following statement by Lichtblau et al. (2015) explains the relevance of assessing the smart factory dimension when investigating production processes. "*The smart factory achieves the highest level of digitization of the value chain through the integration and self-regulation of all processes, especially in production.*"

The smart factory enables flexible production planning and control, which is referred to as **smart operations.** It can be described as the technical requirements in production and product planning to achieve a high level of autonomy. Smart operations are characterized by integrated IT systems that processes and analyses data collected from sensor technology equipped on products and assets in production. Insights from the analysis made from the systems enables forecasts of challenges to the flow of production and preventive measures can be taken. (Lichtblau et al., 2015) Smart operations are considered most relevant to assess by reason of its central role in digitalization and information exchange, specifically in operations.

Smart products are equipped with ICT technologies such as sensors and RFID that collect data on the status of the physical product as well as on its surrounding environment. It enables the product to know its way through production and communicate with IT systems on a higher level resulting in improved production processes that are guided autonomously in real-time. In this way the smart products serve as a foundation for the smart factory and smart operations. Based on the emphasis on production processes within the dimension as well as its important role to facilitate automated, flexible, and efficient production, the readiness is relevant for assessment. (Lichtblau et al., 2015)

The digital technologies are permeated within each chosen dimension. In section 3.3.1, critical enabling techniques were elaborated on and motivated RFID, IoT, cloud computing and big data analytics are all digitalization technologies present in the pursuit of smart factories, smart operations, and smart products. However, the digital transformation that is *enabled* by the technologies is *possible* through the help of **employees**. The employee's workplace gets severely affected by the rapid changes due to digitalization. Consequently, employee skills and a company's effort to acquire new skill sets are readiness measurements that are relevant to understand how to fully utilise digitalization in production processes. (Lichtblau et al., 2015) The relationship between the four dimensions is illustrated in Figure 18.

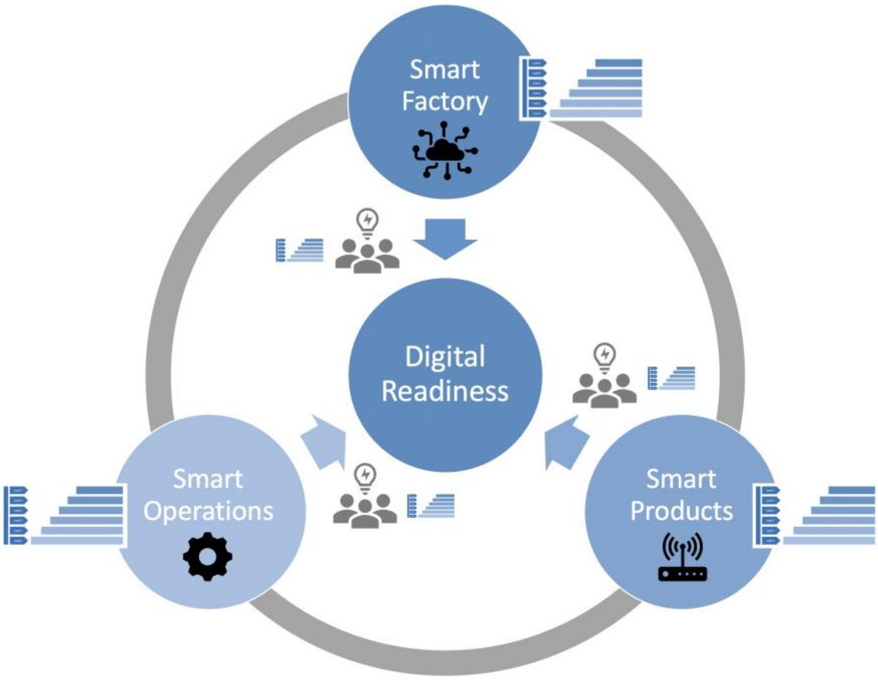

Figure 18. Illustration of the interconnection between smart factory, smart operations and smart products and employees.

3.4.3.2 The excluded dimensions

The reasoning of excluding the two dimensions, strategy and organization, and data driven services, is based on two objectives. First, this master thesis focus area is within operations in Porter's value chain (see section 3.1.1). Second, the selected definition of digital transformation: *"transformation and ongoing digital evolution of a company's organizational structure, business model, products and processes to create value for the company using digital technologies",* from which *processes* is the key word in this master thesis. (Hess et al., 2016; Mazzone, 2014; Stark, 2020; Verhoef et al., 2019)

Data driven service is a concept based on physical or digital components placed on products that generates data from the product in the user phase. The data is then evaluated and analysed for the purpose of optimizing product development and customer experience based on the actual usage of the product. (Lichtblau et al., 2015) From the definition of digital transformation, this can be interpreted as enabling the transformation of a company's *products* to create value for the company using digital technologies and not *processes.* Additionally, the data is evaluated for after-sales services focusing on adding value to services rather than operations. Consequently, the dimension is interpreted as having low impact on the production process and is excluded. Resulting in the exclusion of the dimension since it has a low relevance for measuring Industry 4.0 readiness in operations.

Strategy and organization are central terms based on the statement from Lichtblau et al. (2015): *"Industry 4.0 is more than just improving existing products and processes using digital technologies, it offers the* *opportunity to develop new business models, thus the implementation is of strategic importance".* This statement resonates with the chosen definition of digital transformation for the paper. Although organizational structure and business models are closely related to strategy and organization, this study focuses on production processes. Looking at Porter's (1985) value chain, strategy and organization reach over all supportive and primary activities and are not specific for operations. Obviously, there is the inevitable fact that all terms are interrelated for the total benefits of Industry 4.0 readiness for a company. However, that is not what is to be researched in this master thesis. Therefore, the readiness in strategy and organization are deemed too holistic and extensive for the study and is eliminated from the model.

3.4.3.3 Assessment of Digital Readiness

The method used in IMPULS for evaluating digital readiness is to use a questionnaire with predefined answers that correlates to a specific level. This questionnaire is sent to *one* person at the company for assessing what level in each field the company is at. (Lichtblau et al., 2015)

For assessing a specific dimension's readiness level, the field with the lowest achieved level will determine the dimension's readiness level. To assess a company's overall digital readiness level according to each respondent, the dimension's readiness level will be multiplied with its weight and then summarized. (Lichtblau et al., 2015) For the applied model of IMPULS, the weighted numbers will differ due to strategy and organization, and data-driven services are not included in the applied model. Therefore, the weights used for the applied model are as follows, smart factory 0.23, smart operations 0.16, smart products 0.31 and employees 0.30. The applied weighing system has the same relative importance to each other as the IMPULS model, with the difference that the dimensions strategy and organisation, and data-driven services are not included.

Calculations for assessing the overall Digital Readiness according to each respondent's answers:

$$\sum L_i \times W_i = Overall\ Digital\ Readiness$$

$$L_i = Lowest\ achieved\ level\ for\ a\ field\ within\ dimension\ i$$

$$W_i = Weight\ to\ determine\ importance\ of\ dimension\ i$$

$$i = Each\ of\ the\ assessed\ dimensions$$

The applied model of IMPULS is also sent to *multiple* persons at the same company. Therefore, the digital readiness will be assessed for each of the respondents according to the procedure proposed in IMPULS.

3.5 Summary of the Theoretical Framework

This section aims to summarise the theoretical concepts presented throughout the theory chapter. Furthermore, this section describes how the presented theoretical concepts relate to each other and provides a common ground for answering the purpose of this master thesis.

Section 3.1 provides theories and concepts for understanding the value system and value chain of a company. Furthermore, the section aims to pinpoint the focus area in this master thesis by explaining where in the value system the focus lies. The producing value chain occurs in operations. Hence, operations will be in focus in this master thesis, shown in Figure 19.

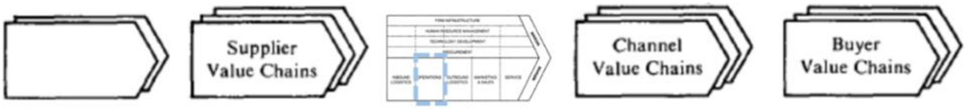

Figure 19. Visualization of 'where' in the value system the focus of this study lies.

Section 3.2 serves as the theoretical foundation for the part of the purpose covering *"...describe and analyse production processes..."*. The section aims to provide theory for investigating how processes are performed in order *"...to identify key objectives for a company going through a digital transformation"*. The central term process is defined, and the theoretical concept of processes are categorized in levels described as process, sub-process and activity. Process mapping enables presentation and illustration of the workflow to understand how processes and activities interact for value creation and further improvements. The theoretical concept chosen for process mapping is called value-based process modelling (VPM) and is shown in Figure 20.

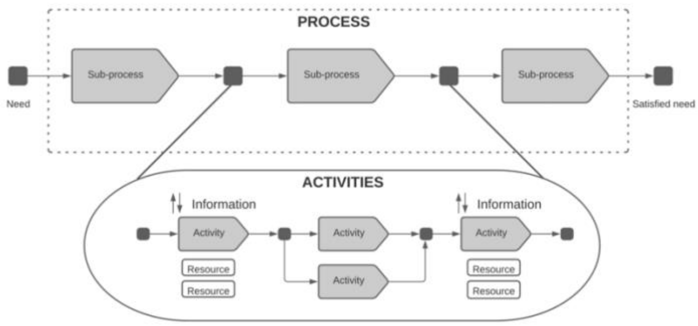

Figure 20. Visualization of value-based process modelling used to describe and analyse production processes.

Section 3.3 has the purpose to cover the theory and concepts behind digitalization, digital transformation and Industry 4.0. The definition of digital transformation in an industrial context, Industry 4.0, is explained and elaborated on. Followed by an explanation of RFID, IoT, Cloud Computing and Big Data Analytics that are technologies with a central role in enabling Industry 4.0. The section aims to provide knowledge and insights of digital technologies to understand digital readiness and digital transformation.

Section 3.4 provides a theoretical model thought to support the part of the purpose that aims *"...to identify key objectives for a company going through a digital transformation"*. For this, an Industry 4.0 Readiness Model is used and applied. A readiness model serves as a framework for measuring a company's current point in the transformation towards Industry 4.0 and apprehends a starting point for further assessment. The model of focus in this master thesis is called IMPULS model. The model measures Industry 4.0 readiness of an organization based on six dimensions. However, the model is considered too extensive for the purpose of this master thesis. Hence, the application of the model is delimited to assess Industry 4.0 Readiness of operations in an organization based on four out of six selected dimensions from the original IMPULS model. See Figure 21.

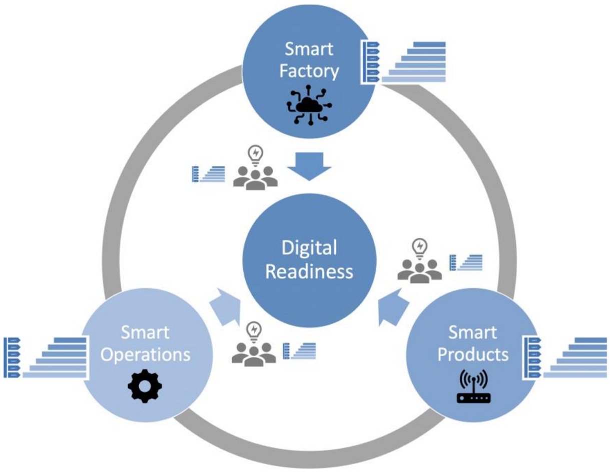

Figure 21. Visualization of the theoretical framework used to assess digital readiness.

The interplay and connections between sections 3.1-3.4 will serve as a foundation for identifying key objectives for a company going through a digital transformation. As illustrated in Figure 22, smart factory relates to the interconnection and communication between processes within the relevant business area, in this case that is within operations in the value system. Smart operations related to the importance of integration and information sharing both internally and externally, thus closely related to the information exchange in the value-based process modelling. Smart products are stated as the foundation of smart factory and smart operations. Smart products collect and send data about the environment, their condition and stage in production. Smart products therefore relate to object in, object out and resources in the value-based process modelling. At last, employees are the resource necessary for each activity to be performed. Further, employees with relevant knowledge and expertise are the key enablers for the smart solutions that needs to be implemented.

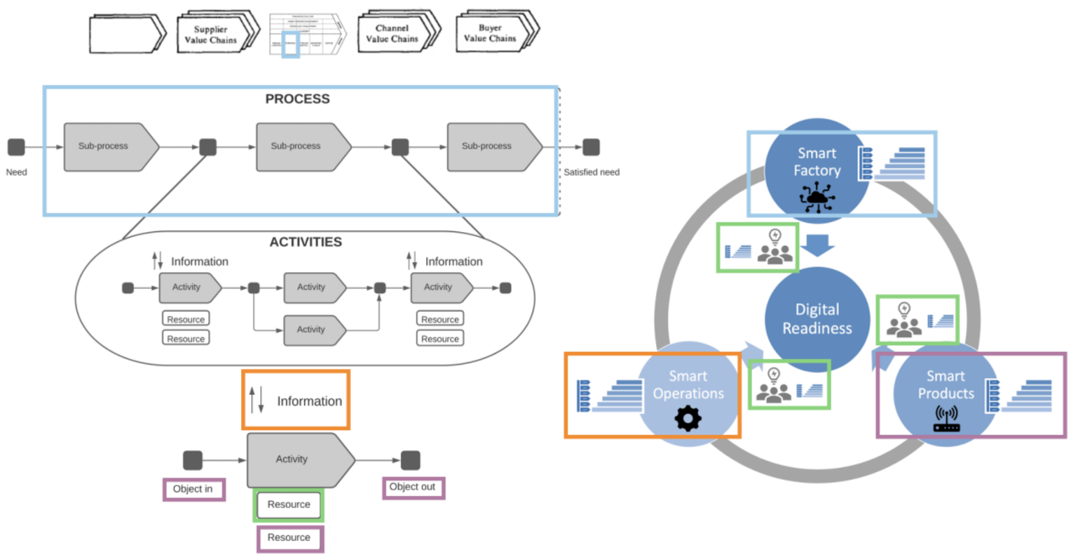

Figure 22. Visualization of the interplay and connections between the theoretical concepts used in this master thesis.

4 EMPIRICS

This chapter aims to present the empirical findings of this master thesis. The chapter is divided into three sections.

The first section provides an introduction to LKAB by presenting its business areas, strategies and ongoing projects. Further, the main processes at LKAB are shortly described. At last, an introduction to the mining method at LKAB is described and the focus of the thesis is illustrated.

The second section aims to describe and visualize the sub-processes and activities within the process 'production loading'.

The third section covers the result and calculations to assess the digital readiness from the questionnaire.

4.1 Introduction to LKAB

Luossavaara-Kiirunavaara AB (LKAB), established 1890 and has been state-owned since the 1950s, picture themselves as a high-tech mining and mineral group that mines and processes iron ore for the global steel market. (LKAB, 2019) The business concept is to manufacture and deliver upgraded iron ore products and services from the ore fields in northern Sweden. (LKAB, 2019) LKAB is decentralized in two separate business areas, *Iron Ore* and *Special Products*. Iron Ore business area is further divided based on the location of extraction. LKAB has three mines. Two underground mines, one in Malmberget and the other one in Kiruna, and additional open-pit mining in Svappavaara. The mine in Kiruna is in focus for this master thesis. (LKAB, 2020b)

The special products business area includes LKAB Minerals, LKAB Wassara and LKAB Berg & Betong. These are corporations have been established as a result of successful research and development at LKAB ensuing new profitable business areas, e.g., being the world's largest producer of shotcrete and marketing unique water-powered drilling systems. (LKAB, 2020b)

The business area Iron Ore stands for 92% share of net sales. The total net sales of 33,915 MSEK and an operating profit of 11,654 MSEK. (LKAB, 2021) LKAB is a small player on the global iron ore market but the second largest supplier of seaborne import for iron pellets. Customers are mainly in Asia, Europe, Middle East and North Africa. (LKAB, 2017)

LKAB has an extensive digitalization strategy with the aim of revolutionizing the mining industry. The technological development and digitalization focus not only on product development, but also to the development of new production processes. The aim is to, through digitalization, automation, electrification and new operations methods set the base for a dioxide-free production and a new standard for mining. (LKAB, 2020a)

In addition, LKAB has to start mining deeper down in the mines due to current haulage levels expected to be emptied by 2030s. To continue being a competitive company, a project called Sustainable Underground Mining (SUM) was initiated in 2018 for efficient, safe, carbon-free and digitalized autonomous mining at great depths. The project is a collaboration between ABB, Epiroc, Sandvik and Combitech. Various tests and solutions are currently in development that call for insights for the future implementation into the production, set to occur 2022-2030. (Sustainable Underground Mining, n.d.)

4.1.1 Primary activities at LKAB and the focus of this thesis

For LKAB, and the mining industry, the primary activities defined by Porter (1985) are trickier since the traditional flow of product going through inbound, operations and outbound are not applicable to mining companies. The main processes related to the production of iron ore are *exploration*, *mining*, *processing* and *transport*, illustrated in Figure 23. (LKAB, 2020a)

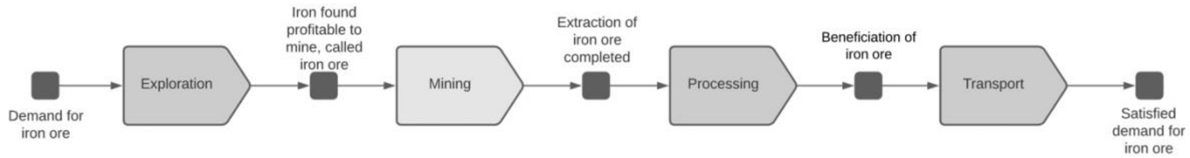

Figure 23. Illustration of the main processes within the Iron Ore business area in Kiruna mine. The main processes enable the delivery of iron ore to customers.

Exploration is the basis for iron ore. Exploration is the work to secure access to raw material and mineral reserves for future mining operations. Exploration is performed with test drillings and studies to accumulate information of potential future mining sites. (LKAB, 2020a)

The **mining** process is the heart of operations where the *ore* is mined. Ore is defined as an economic term for a mineral that is deemed profitable to mine. Mining can be divided into the processes of *drifting*, *production drilling & blasting*, *production loading*, *chute loading & transport*, *emptying & crushing* and *hoisting*. Mining is covered in detail in section *4.1.2 Introduction to the mining method.* (LKAB, 2020a)

Processing is the beneficiation, or upgrading, of the ore into high-quality iron ore products. Processing should not be mixed with the word processes, used to express the different set of activities a company walks through to realize a business goal. Processing is divided into the sub-processes of *sorting*, *concentrating* and *pelletising*. The work through is illustrated in Figure 24. However, it will not be described further in detail. (LKAB, 2019)

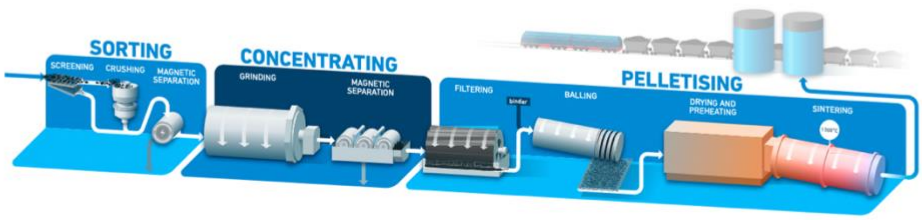

Figure 24. Illustration of the processing of the ore. (LKAB, 2019)

Lastly, **transportation** takes place and transfers millions of tonnes of iron ore products to the ports of Narvik and Luleå every year. The ore is transported along the Ore Railways before shipped to the global market. (LKAB, 2019)

Operations is, according to Porter (1985), summarized as activities relating to transforming inputs into the final product form, e.g., machining, packaging, assembly, maintenance and facility operations. Therefore, *operations* of LKAB are defined as the combination of mining and processing to produce high-quality iron.

4.1.2 Introduction to the mining method

The mine in Kiruna is an underground mine and uses the mining method named sub-level caving. The principle of sub-level caving is to create cavities in the orebody, and with the use of gravity, let the ore fall down to underlying levels from where the ore can be efficiently loaded and transported for processing. The method is divided into six processes, *drifting (1)*, *production drilling & blasting (2)*, *production loading (3)*, *chute loading & transport (4)*, *emptying & crushing (5)* and *hoisting (6)*. Processes are shown with illustrations in Figure 25. (LKAB, n.d.)

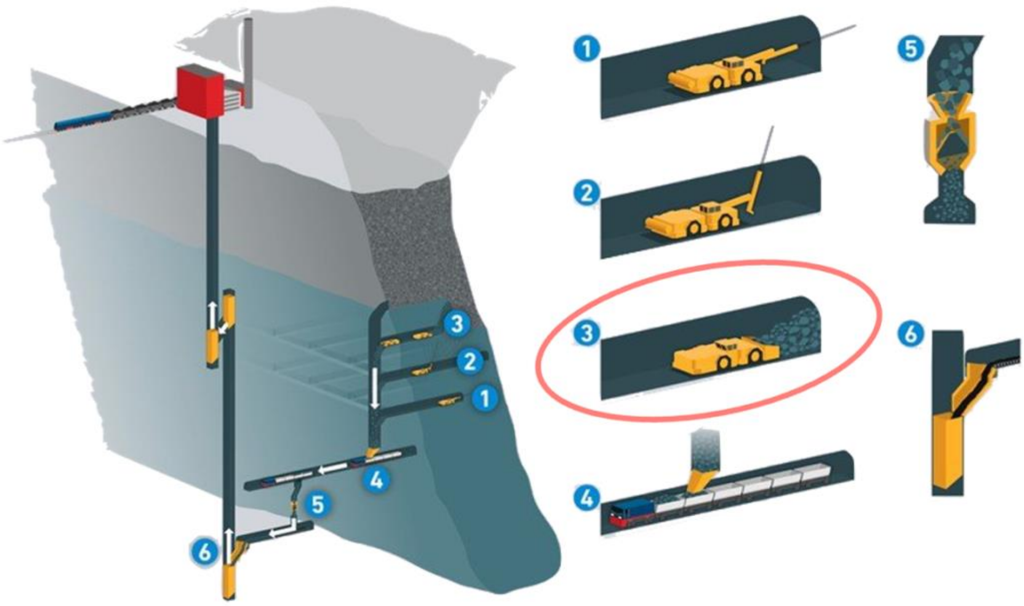

Figure 25. Illustrations of the different processes in mining, where the third process production loading will be the focus of this master thesis. (LKAB, n.d.)

First, *drifting* is performed to establish the transport routes parallel to the orebody, known as drifts. From the drifts, development drifts are blasted directly into the orebody to prepare for the large-scale mining. Development drifts are the *tunnels* where ore is extracted while drifts are the routes to and from tunnels. (LKAB, n.d.)

When the development drifts are in place, the *production drilling & blasting* are performed. Holes, measuring up to 55 meters, are drilled upwards into the orebody from the furthermost end to the entrance of the tunnel with some distance between them. Each fan-shaped cross section, shown in Figure 26, in the tunnel is called a *ring*. The rings are then loaded with explosives to create cavities in the orebody and enable ore to be mined in a productive way. The drilling is remotely controlled by a drilling unit. (LKAB, n.d.)

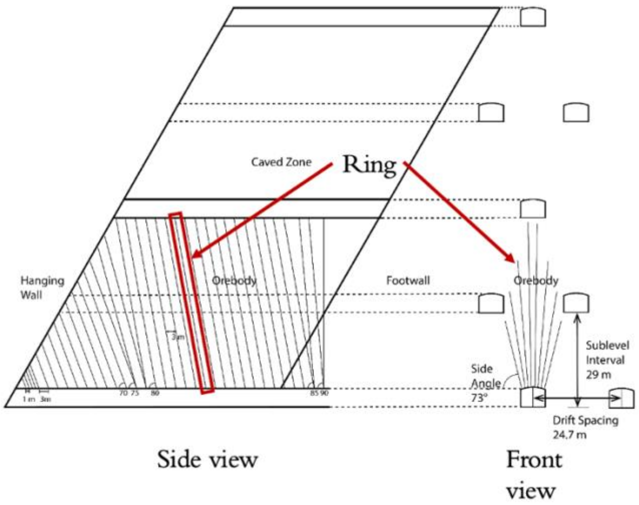

Figure 26. Illustration of rings and how it relates to the drifts and tunnels. (Shekhar, 2020)

When the blasting is performed and ventilation completed, the *production loading* starts. The blasted ring enables a flow of rocks to fall to the ground where it is accessible for loading machines, called *LHDs (Load-Haul-Dump machine)*. The ore is then transported and dumped into shafts, known as ore passes. Thereafter, the LHD comes back for more ore. This is done in a repetitive manner until the ring is considered closed and the next ring should be blasted. The constant flow of rocks entails a high productivity since the interruptions of blasting is minimized. (LKAB, n.d.) The process of *production loading* will be in focus for this master thesis and is covered in detail in section *4.2 Description of the Production Loading process*.

In the ore passes, the ore falls to huge crushers where large rocks are reduced in size for simpler handling. The ore is *chute loaded & transported* to the main level with the use of driverless trains. The main level in Kiruna is 1,365 meters below the mountain top. At the main level there are offices and workshops. (LKAB, n.d.)

From the trains, the ore is then *emptied* and delivered to *crushers* for additional breakdown of the ore into pieces measuring 10 centimetres in diameter. The ore is then transported on long conveyor belts to the skip hoists that transport the ore to the surface for further processing. (LKAB, n.d.)

4.2 Description of the Production Loading process

This section aims to provide information about the production loading process. First, the mapping of the production loading process is illustrated with its sub-processes in Figure 27. Thereafter, each sub-process is covered in its own section. This is followed by sections to elaborate on main resources and main information used for all of the different sub-processes. These resources and information are covered in their own sections due to being interrelated to each other and cannot be said to be specific to a certain sub-process.

The loading process is simple to explain but hard to perform in practice[1]. The loading process is a continuous process[2]. It can therefore be discussed where the process begins.

For this study, the loading process is set to be initiated during the planning phase, deciding where, how much and when to load. The following *production loading* is the actual extraction of the ore

[1] Production Manager 1 at LKAB, Interview 23rd March 2021; Production Manager 2 at LKAB, Interview 23rd March 2021.
[2] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

performed on a daily basis. During the production loading, the ore is loaded onto the LHDs bucket and transferred to the ore passes for further transportation. This is performed if the flow of ore is sufficient, otherwise the production loading is ended. The final step of the loading process, *follow-up on the outcome* is thought as the phase for ensuring targets are being met and continuous improvement. Figure 27 presents the flow of the sub-process on a convenient level for understanding how it is performed.

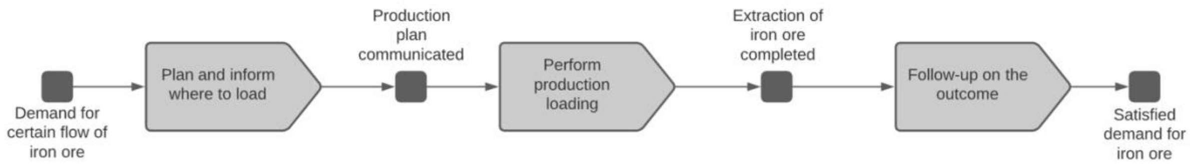

Figure 27. Value-based process model of the sub-processes "plan and inform where to load", "perform production loading" and "follow-up on the outcome" within the loading process.

4.2.1 Description of sub-process *plan and inform where to load*

This section aims to describe the mine planning process for production loading. Today, a lot of the work is structured in long-term plans becoming more and more specific as the shorter the time frame becomes. However, the focus of explanation will be on the development from a monthly to a daily plan. The work between documents results in a lot of manual handling, as to be described. Further, the estimation of ore to be extracted is described as well as the communication between divisions during the planning phase.

The open plan is a planning document that acts as support to the decision on what rings should be loaded during a certain time frame. It visualizes what sequence the rings in each area should be blasted and loaded. It is accessible both digitally and physically as a map in the mine control room.[3] The open plan is shown in Figure 28.

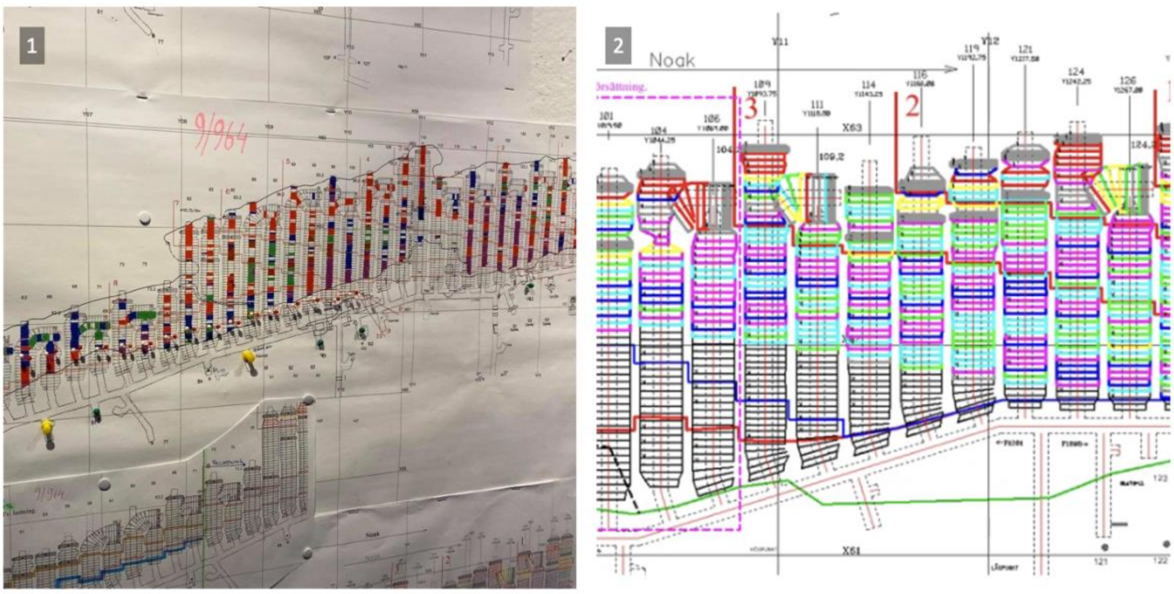

Figure 28. Showing the open plan both physically (1) and digitally (2). (Observation notes, observation 1)

[3] Mine planner and layout specialist at LKAB, Interview 16th April 2021.

Monthly plan

Each month, the mine planners use the open plan as support for picking out a certain number of rings according to the planned sequence to achieve a monthly production target in tonnage. The documentation of rings intended for production as well as the calculation of planned tonnage is performed in Excel. The *planned tonnage* to be extracted is estimated by combining the *theoretical tonnage* with the *extraction ratio*.[4] The relation between the three terms is shown in Equation 1.

$$\frac{\textbf{Planned tonnage}}{\textbf{Theoretical tonnage}} = \textbf{Extration rate} \quad (1)$$

Theoretical tonnage is an estimation from the geologists in the prospecting phase on how much ore that can be extracted. The extraction ratio is the estimation from the mine planners. Information from previously loaded adjacent rings is used as a decision support for assessing the extraction ratio of the studied ring. Furthermore, it can be adjusted with regards to the complexity of the ring. Such as if it is the last one in a sequence. Additional factors affecting the production rate, and thereby planned tonnage, are transportation distance from ring to ore pass, ore pass availability and rock restrictions. Currently, there are no methods for calculating these parameters, rather they are evaluated and estimated with experience and "gut-feeling".[5]

Weekly plan

The weekly plan aims to further divide the monthly plan in production goals on a weekly basis. This enables follow-up and ensuring that the extraction goal is fulfilled. Once a week, mine planners and mine control get together for a meeting to agree on this weekly production plan. Mine planners present rings from the monthly plan to the mine control that expresses eventual objections on the suggestion. After an agreement, the rings are inserted manually in the information system GIRON, where it is accessible for mine control to schedule the daily operations.[6]

Daily plan

The mine planners do not schedule the daily work but present what rings to be loaded each week to mine control that in turn schedules the daily operations. Thus, the mine control creates a shift plan for each day according to the specified rings intended for production in the weekly plan. At last, to communicate the shift plan to operators. The mine control makes a loading schedule for the shift-team of operators to use during the shift.[7] Examples of what is included in a loading schedule are what tunnels a specific LHD should load from and to which ore pass it should dump into. If needed, an informative comment is left to clarify the daily work. For example, a notice of a disruption such as an ore pass being out of function (Observation notes, observation 1). The shift plan and the loading schedule is shown in Figure 29.

[4] Mine planner and layout specialist at LKAB, Interview 16th April 2021.
[5] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[6] Mine planner and layout specialist at LKAB, Interview 16th April 2021.
[7] Mine planner and layout specialist at LKAB, Interview 16th April 2021.

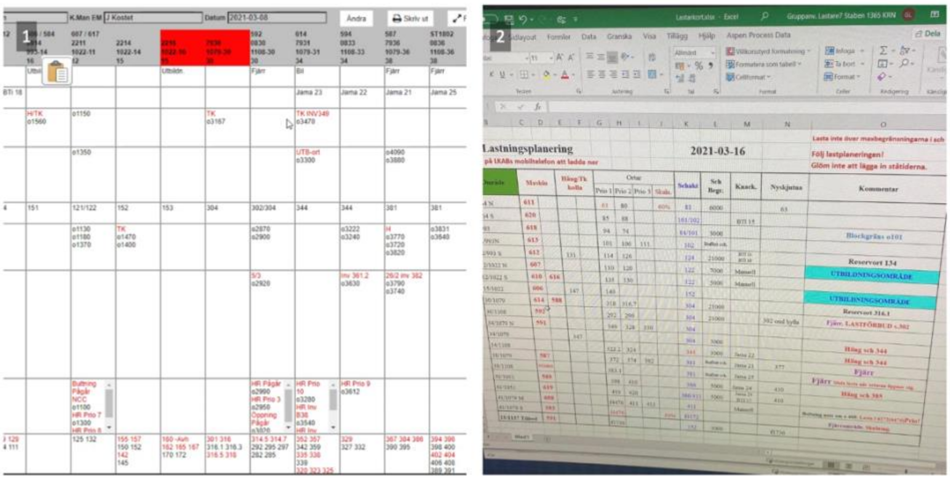

Figure 29. Showing the shift plan (1) and the loading schedule (2). (Observation notes, observation 1)

During the shift, the operator logs production information. For example, the completion of a ring or downtimes due to disruptions. The information is then used by mine control to manually update planning documents to keep track of how the production progresses. Typically, mine control needs to update the daily shift plan and the weekly plan separately and check so that they correspond. The updates are in turn used by mine planners as support for creating the next weekly or monthly plan.[8] The breakdown of all planning activities during the planning phase as described are shown in Figure 30.

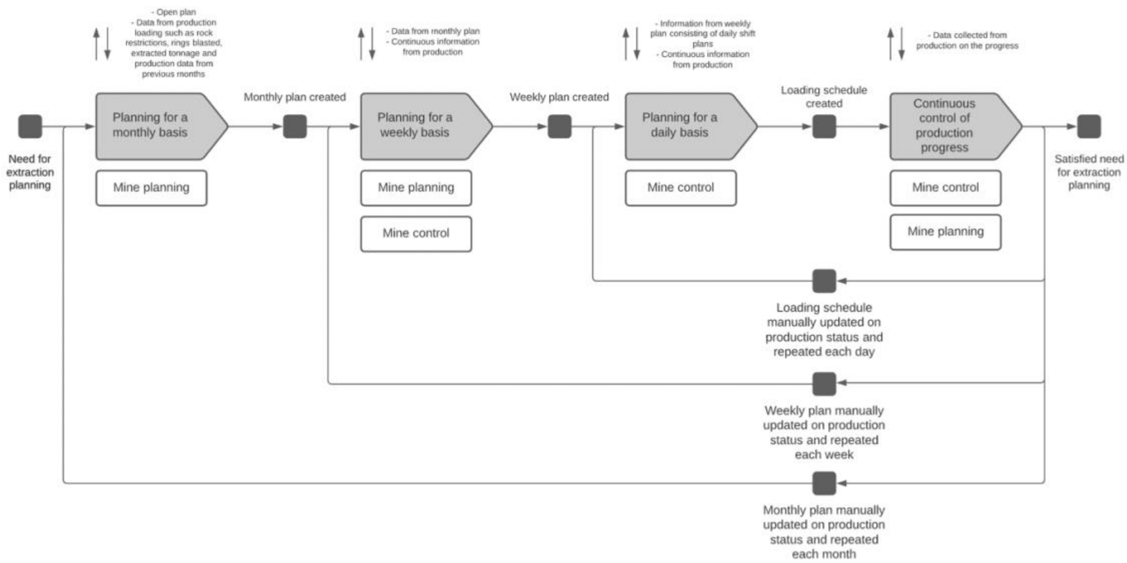

Figure 30. Value-based process modelling of the activities within the sub-process "plan and inform where to load".

The planning phase consists of four different control documents with different information. It is expressed that a platform integrating the documents would decrease much of the inefficient manual updating and double handling.[9] Except for the inconvenient updating that needs to be done in the separate documents, it also entails difficulties in the ease of use. For example, the shift plan and loading schedule is available for all operators to view in their cell phones through an app

[8] Mine planning Engineer at LKAB, Interview 10th March 2021.
[9] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

but on different sheets. If the sheets could be integrated in one interface, the operator could avoid the struggle of going back and forth to find the right information.[10]

Additionally, an issue today is that the reasons for downtimes are seldom known the same day. Consequently, they are summarized and presented at the end of the month instead of the end of the week. If the reasons were known the same day, it could serve as a basis for follow up to the next week's production plan instead of the monthly plan.[11]

Communication between divisions in the planning phase

Further, there are problems with coordination and communication between units when it comes to planning. Numerous tasks are planned and performed independently and incoherently. Production, road maintenance or reparation of an ore pass can be planned for the same time without it being communicated between the different responsible units. The operational problems that occur due to this lack of communication has grown to a desire for a common platform used by all units. An interconnection of tasks and collective consultation of planned work would enable things to be performed in accordance with each other to make the tasks coherent. An example would be that the production plan made by the mine planners would take supporting functions e.g., maintenance into account. In the other way around, the production plan would be available on this platform for other units to plan their work.[12] The issue is also expressed by the operators and production managers. Lack of coordinated planning results in additional idle time that could have been avoided.[13]

4.2.2 Description of sub-process *perform production loading*

Perform production loading is one the most crucial sub-process at LKAB for its impact on productivity and the internal value chain. The actual operation of production loading consists of the activities: secure conditions and unforeseen obstacles, loading, haulage, dumping and decision upon closing the ring. Each of these activities is covered in its own section.

The activities for performing production loading are illustrated in Figure 31. The VPM for production loading can also be found in Appendix D for greater resolution. Each activity is shown individually in the respective section regarding the activity, with the description of its object in, object out, information and resources.

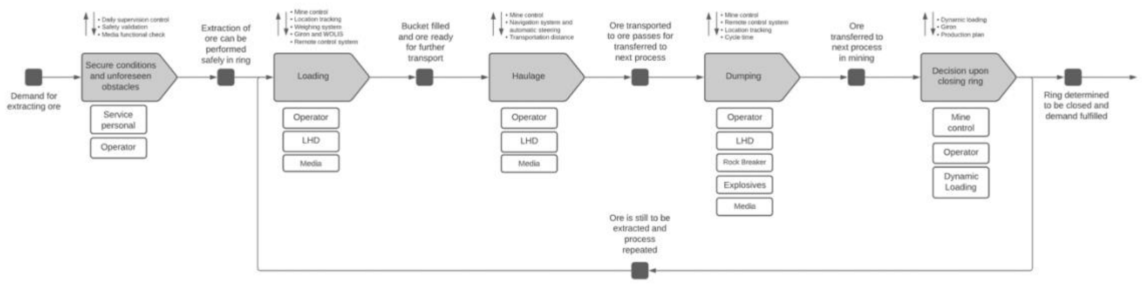

Figure 31. Value-based process model of the activities within the sub-process "production loading" using the value-based process modelling approach.

[10] Operator at LKAB, Interview 23rd March 2021.
[11] Mine planning Engineer at LKAB, Interview 10th March 2021.
[12] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[13] Production Manager 1 at LKAB, Interview 23rd March 2021; Production Manager 2 at LKAB, Interview 23rd March 2021.

4.2.2.1 Secure conditions and unforeseen obstacles

The activity *secure conditions and unforeseen obstacles* are shown in Figure 32 with its resources, information, object in and object out.

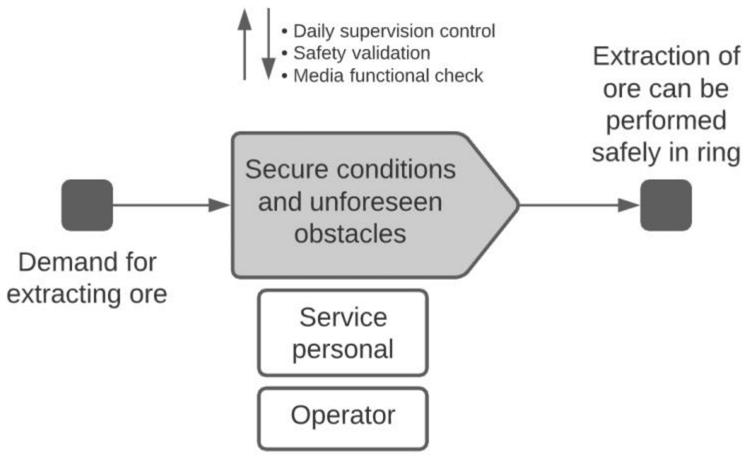

Figure 32. Value-based process model of the activity secure conditions and unforeseen obstacles.

Before, during and after production loading, there are numerous potential obstacles that need to be secured for loading to be efficient and safe. First, the toxic gas that develops in connection with the blasting, needs to be ventilated before any human can enter the area. It takes 3-4 hours for the ventilation to be completed, it potentially results in machines and workers being idle.[14]

When the toxic gases are ventilated, there are certain checks to be done before the production loading can be started. Service personnel are contacted to validate the safety of the blasted ring. This safety validation is performed every third day until the ring is closed and no more ore can be extracted. The service personnel are manually contacted by the mine control via an email containing what rings need to be checked that day. The service personnel validate the ring and contact the mine control that marks it as verified and available for operators to enter.[15] Meanwhile the service personnel are securing a drift, operators are directed to work in tunnels already checked. This method for sharing information is also used for other types of maintenance and renovations in the mine. (Observation notes, observation 1)

The operators get instructions to check things before, during and after the work shift. All these tasks are summarized in a daily supervision consisting of 22 tasks (Education Material LKAB, 2011). Before a shift starts, there is an overlap in the schedule dedicated for briefing between the operators. This briefing often contains information about the recent shift and if there have been any interruptions as well as heads-up for coming interruptions. After the briefing, the operator must drive through the area in a car before entering with an LHD. During this drive, the operator identifies where other employees are working and who is doing the work.[16] The drive itself often takes 3-5 minutes. Further, before production loading can be started, the status of the loading area should be checked. Media, meaning devices storing and delivering data, is checked to be functional. The ventilation system must be confirmed to be switched on as well as that the ventilation cloths are intact. The roads where the LHDs drive needs to be examined so that there are no damage or

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[14] Research Engineer at LKAB, Interview 5th March 2021.
[15] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[16] Operator at LKAB, Interview 23rd March 2021.

water-filled pits. The quality of the roads is one of the most important factors that affect the LHD's capacity and service life as well as the driver's working environment. On the roads, the logs that protect cables from chafing against rock walls or corners need to be checked so that no electric equipment is damaged. (Education Material LKAB, 2011) For the LHD's, routine checks should be done manually to check the status of the LHD, e.g., looking for punctures, oil leaks, abnormal values on instruments etc.[17](Education Material LKAB, 2011) Finally, the operator needs to signalize that production loading is to be performed by closing the gate to the area as well as letting others know that the specific LHD belonging to the operator is in the production area by putting the number-tag for the vehicle on the gate.[18] Some of the tasks for the daily supervision are shown in Figure 33.

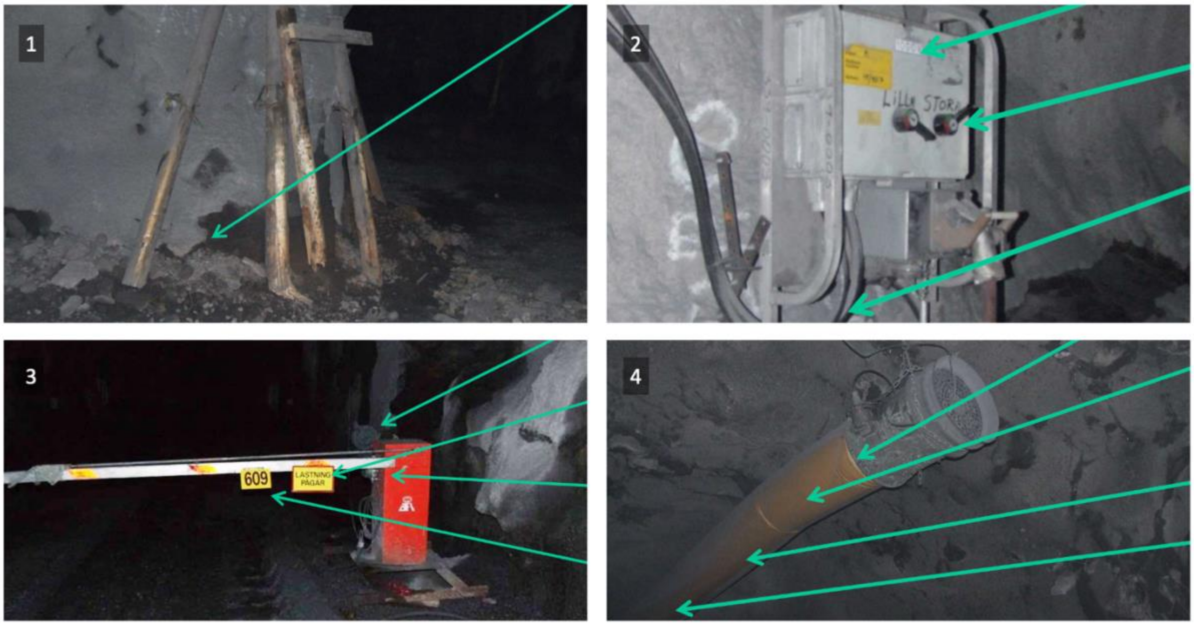

Figure 33. Showing some of the tasks for the operator to investigate before starting the loading. The green arrows point at different security checks. Logs protecting cables from chafing (1). Media control (2). Gate control (3). Ventilation check (4). (Education Material LKAB, 2011)

The operator has the tasks to be checked *"in the back of my head"* and performs the supervision by walking round the LHD and scans the LHD so that everything looks right. Some of the *more important* tasks are checked closely, e.g., logs and gates being functional.[19] A daily supervision protocol exists (Education Material LKAB, 2011) but is not used widely[20]. Instead, when the shift is over, the operator should brief the next operator. Due to the supervision being done mainly in the head by the operator, the information passed to the next operator can sometimes be insufficient.[21]

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[17] Production Manager 1 at LKAB, Interview 23rd March 2021.
[18] Operator at LKAB, Interview 23rd March 2021.
[19] Operator at LKAB, Interview 23rd March 2021.
[20] Operator at LKAB, Interview 23rd March 2021.
[21] Operator at LKAB, Interview 23rd March 2021.

4.2.2.2 Loading

The activity *loading* is shown in Figure 34 with its resources, information, object in and object out.

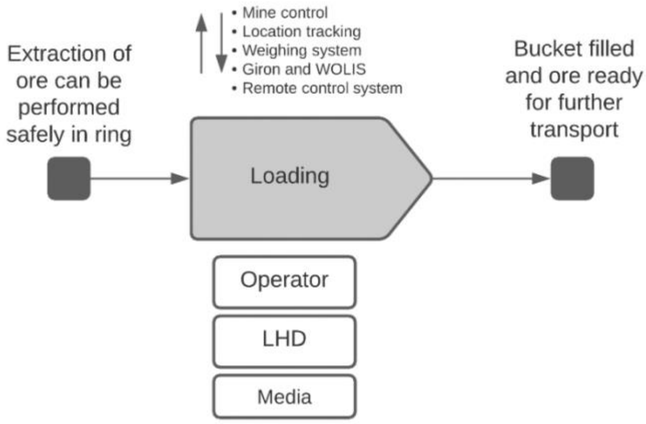

Figure 34. Value-based process model of the loading activity.

The loading of the bucket is always controlled by an operator, either that sits inside the LHD or remotely controls the LHD.[22] The fleet consists of both manual and semi-automatic LHDs. For the manual ones, loading, hauling and dumping is performed by a human operator from inside the LHD. For the semi-automatic ones, loading is performed remotely by a human operator and the haulage and dumping is automatic.[23]

The rock loaded is ore. Ore is a valuable mineral and can be extracted profitably. Gangue is the residual product and is a commercially valueless material. Depending on the quality of the blasting, there are different loading strategies. These strategies have evolved to maximize the extraction of ore depending on aggravating circumstances such as hang-ups, stop or uneven flow of rock. (Shekhar, 2020) Illustrations of these circumstances are shown in Figure 35. Another problem related to the load of the bucket, is that the operators are filling the buckets too heavy, causing the LHDs to require more maintenance than needed.[24]

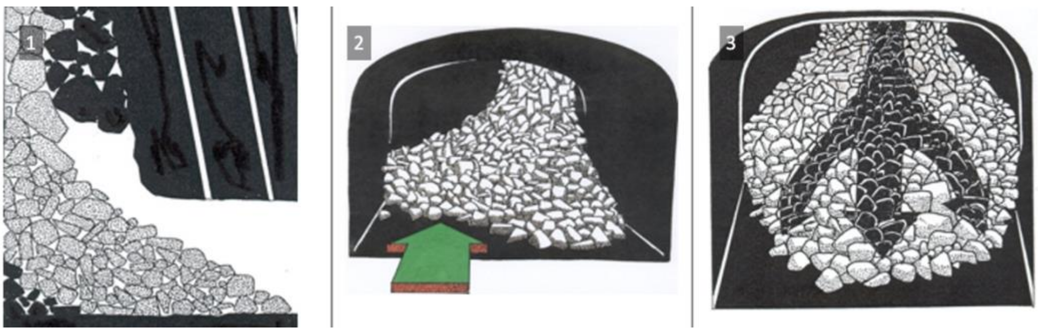

Figure 35. Illustrations of a variety of circumstances that affect the loading strategy. Hang-ups (1), uneven flow of rock (2) and ideal circumstances (3). (Education Material LKAB, 2011)

To support the operations there is some information collected during the activity of loading the bucket. The location of the LHD is tracked. Partly for monitoring what the LHD loads in which

[22] Research Engineer at LKAB, Interview 5th March 2021; Production Manager 1 at LKAB, Interview 23rd March 2021.
[23] Production Manager 1 at LKAB, Interview 23rd March 2021.
[24] Mine planning Engineer at LKAB, Interview 10th March 2021.

drift to enable follow-up to be made, but also for safety concerns to know each operator's position. The weight of the bucket is also collected, used as decision support for the operator, discussed more in section *4.2.2.4 Decision upon closing the* ring.[25] (Observation notes, observation 1)

4.2.2.3 Haulage

The activity *haulage* is shown in Figure 36 with its resources, information, object in and object out.

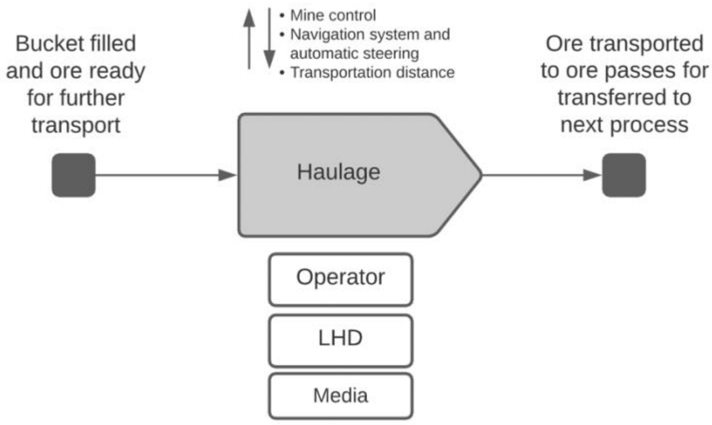

Figure 36. Value-based process model of the haulage activity.

After the bucket is loaded, the ore is hauled to an ore pass either manually by an operator from inside the LHD or automatically with the semi-automatic, remotely controlled, LHDs. Semi-automatic LHDs travel with a built-in navigation system through predefined routes whereas the manual LHDs are navigated by the operator. Obstacles on the travel route are detected by a sensor system in the semi-automatic LHD as opposed to a manual LHD where a human operator can identify these visually.[26]

Both types are equipped with a communication system that tracks the position of the LHD in the mine. In that way, it can be monitored from which tunnel the LHD loads from and which ore pass it transports the ore to. The communication system is wireless and based on RFID technology. Strategically placed readers in the mine detects feedback signals from tags placed on the LHDs. The signals are transmitted via an antenna on the LHD.[27]

There have been problems with the communication system which complicates the tracking of the LHD. The subsystems are dependent on each other in a semi-automatic LHD e.g., if the location of the LHD is not known the overall system fails to function. Resulting in all system breaks, including navigation, and the transport stops which entails expensive malfunction. In contrast, the subsystems in a manual machine are independent of each other, an LHD can be navigated by an operator despite the communication system being shut down.[28]

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[25] Research Engineer at LKAB, Interview 5th March 2021.
[26] Research Engineer at LKAB, Interview 5th March 2021.
[27] Research Engineer at LKAB, Interview 5th March 2021; Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[28] Research Engineer at LKAB, Interview 5th March 2021.

4.2.2.4 Dumping

The activity *dumping* is shown in Figure 37 with its resources, information, object in and object out.

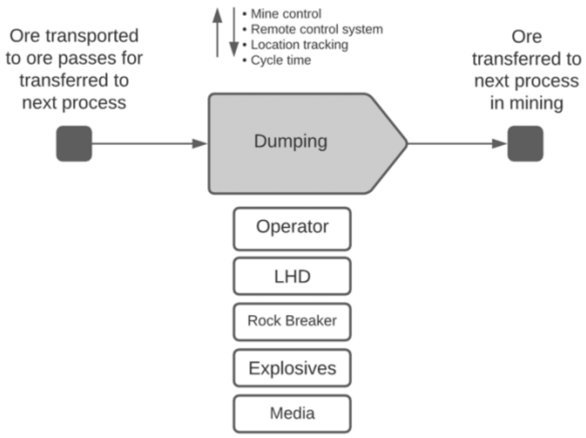

Figure 37. Value-based process model of the dumping activity.

The last activity, before either loading another bucket or closing the ring, is to dump the ore into an ore pass followed by further transportation. If using a manual LHD, the dumping is performed by an operator inside the LHD. For the semi-automatic LHD's, the activity is automatic and performed without human interaction.[29]

The ore pass has a grid to prevent big rocks from falling through. This is due to the largest rocks being too big for the crushers to handle. Instead, if rocks are too big to enter, a rock breaker is used to break the rock further before going through. The rock breaking is done in most cases by a stationary rock breaker and the operation is performed remotely, surveyed through video. Some ore passes do not have a stationary rock breaker, for those instances, a mobile rock breaker is used. The two rock breakers are shown in Figure 38. Occasionally, rocks are too big for the rock breaker. Then, the rock is taken aside and blown in smaller pieces.[30] (Observation notes, observation 1)

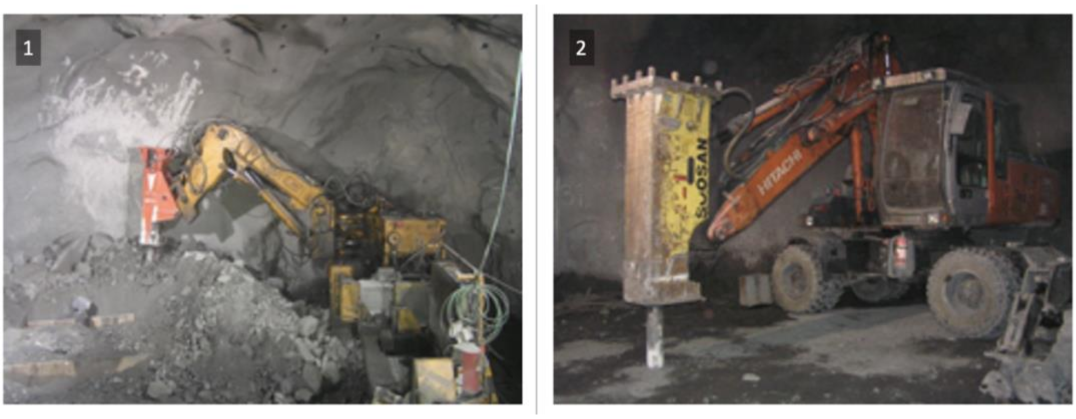

Figure 38. Pictures showing a stationary rock breaker operated on remote (1) and a mobile rock breaker operated locally (2). (Education Material LKAB, 2011)

Last years, problems with the ore passes emerged. The ore passes breaks, which has led to the problems with the transportation distance increases and stockings may appear, which has a

[29] Production Manager 1 at LKAB, Interview 23rd March 2021.

[30] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

negative effect on the productivity. This results in the northern part of the mine being more productive than the south part, as the problems have arisen in the south. For the operators, and production managers, this has led to increased pressure to load from the northern part to compensate for the loss in the southern part. This is due to them trying to maintain the right amount of tonnage planned to be unloaded.[31]

4.2.2.4 Decision upon closing the ring

The activity *decision upon closing the ring* is shown in Figure 39 with its resources, information, object in and object out.

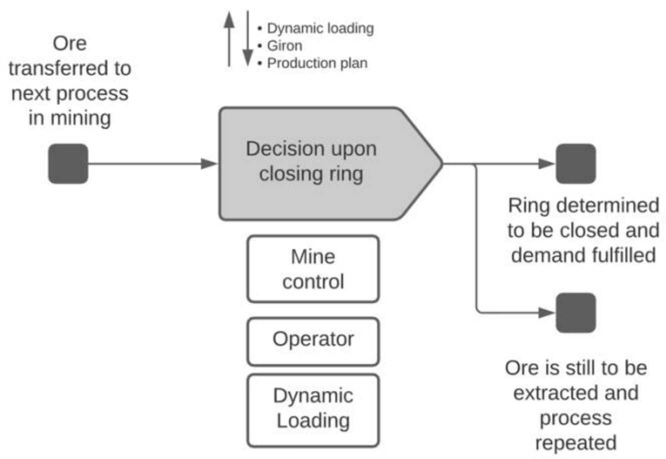

Figure 39. Value-based process model of the activity decision upon closing the ring.

As soon as the ore from the ring is not profitable to load anymore, the ring is closed, and the operator notifies the mine control. For the operator, it is important to realise when to stop the production loading and instead close the ring to initiate a new blasting that makes more ore available. This to minimize the extraction of gangue. The operator themselves, or together with the mine control, takes the decision to abandon the ring after a visual inspection. However, a recent implementation of a decision support system referred to as *dynamic loading* has been used for supporting the operator's decision.[32]

Dynamic loading uses an economic model that calculates the profit from ore extracted and supports the operator to know when to stop the loading process. This is performed by monitoring extraction rate and iron content in loading, together with related costs. As the iron content decreases, it becomes less profitable to load the minerals and the process should be stopped. The operator monitors the progress by looking at the slope of the curve and has a "box of decision" to support when to abandon the ring, as shown in Figure 40. The implementation of dynamic loading has been successful and led to more ore being extracted with better quality than before.[33] Even though proven successful, it is not used by all operators. Some operators are positive to the system and think it is supportive when taking the decision whether to abandon the ring or not. Others rather want to believe in their own experience of when to stop load and close the ring.[34]

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[31] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[32] Mine planning Engineer at LKAB, Interview 10th March 2021.
[33] Mine planning Engineer at LKAB, Interview 10th March 2021.
[34] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

There are potential improvements with the system. As for now, the operators driving the LHDs manually do not have access to dynamic loading on a screen in the LHD. As a result, they get updates from mine control on the status of the ring. Alternatively, they check the system during their breaks or stops and check the status on their cell phone. Another improvement area is to calibrate more accurately, e.g., by measuring volume of bucket, to provide better support on decisions and a more detailed truthful profit calculation.[35]

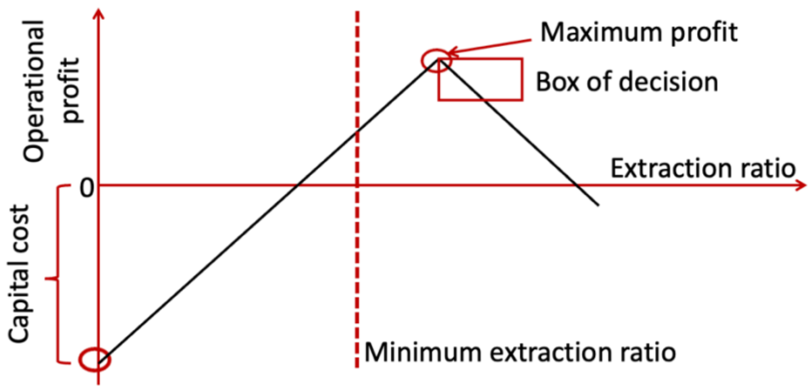

Figure 40. Showing the illustration that the operators face to support their decision to abandon or to continue to load from the ring.[36]

Up until recently, it was difficult for the mine planners to investigate the reason a ring was closed. They had to talk directly to the operator who closed it, which of course made the follow-up and validation of the planning time consuming and difficult. Currently, the operators have the *option* to comment the decision to close a ring in an IT-system. Simplifying the process to follow-up and analyse data. However, since it is still optional to enter the comment, many operators do it undemand.[37]

4.2.3 Description of sub-process *follow-up on the outcome*

To secure the performance of production loading, and to ensure the planning is accurate, a follow-up on the outcome is needed.[38] Up until recently, the only analysis of the outcome has been to investigate how the extracted tonnage per month complies with the plan. However, this analysis is experienced as insufficient and there has been extensive work to improve the quality of the data to enable more detailed analysis to be performed. Instead of looking at the mine as a whole, different areas of the mine are analysed separately. Also, the interval of data analysed is changed from monthly to daily. Currently, there is limited automated analysis. However, there are systems recently implemented such as Power BI to provide mine planners with information on production rate, iron content and reasons for disruptions. Also, it exists tests for further expansion of using automated analysis solutions. Today, a lot of the follow-up is performed by looking at the extracted tonnage and then manually analysing the data to understand why a certain extraction ratio was higher or lower. This is thought to be able to be performed automatically.[39] The activity to perform follow-up according to VPM is shown in Figure 41.

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[35] Mine planning Engineer at LKAB, Interview 10th March 2021.

[36] Mine planning Engineer at LKAB, Interview 10th March 2021.

[37] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

[38] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

[39] Mine planning Engineer at LKAB, Interview 10th March 2021.

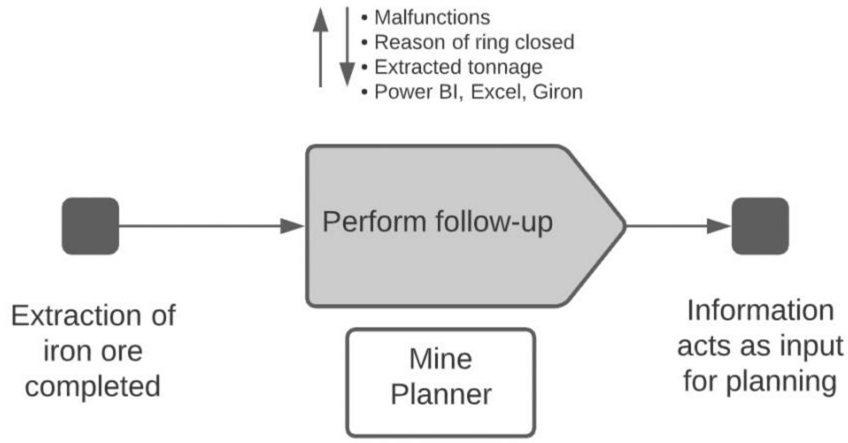

Figure 41. Value-based process model of the activity to perform follow-up.

4.2.4 Description of the main resources

Resources are what is needed for the activity to be performed. For the production loading process, the main resources are the *employees*, the *LHD's* and the *media* to enable information and communication. All main resources have in common to be involved in most of the activities previously discussed.

4.2.4.1 Interviewees reflections on employees

Employees at LKAB are both receptive and reluctant to the digital transformation. On one hand, employees are in general described as positive to digital technologies as they understand that they are vital for the organization and that LKAB will fall behind in competitiveness if productivity is not improved since the operations deeper down in the mine are more complex. Furthermore, the widespread usage of IT and apps in everyday life has also increased the understanding among employees on what improvements digitalization can do to make tasks easier.[40]

On the other hand, employees particularly within the production, have been described to be hostile to the change.[41] Even though the workers have been trained and educated in the new systems, and the benefits of the tools have been communicated, there are employees that do not like the change.[42] One statement expressed as a potential explanation for the employee's hostility, is that there are currently many projects going on at LKAB where some are completed, and others are abandoned. It is therefore experienced as frustrating when several tests are done in their working environment that does not lead to anything fruitful. To prevent this phenomenon, the use of a central decision-making unit is expressed to potentially be useful for prioritizing among projects as well as assessing whether the projects that are intended for launch are feasible with respect to their current state.[43] Another explanation is that the opinion among some employees, often elderly and more experienced, is that new technologies are unnecessary and not preferable to previous ways of working. Additionally, some technologies such as *dynamic loading*, the decision support systems for loading, are misinterpreted to replace their line of work. Misinterpretations like this

[40] Research Engineer at LKAB, Interview 5th March 2021.
[41] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[42] Mine planner and layout specialist at LKAB, Interview 8th March 2021; Mine planning Engineer at LKAB, Interview 10th March 2021.
[43] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

results in a certain degree of hostility.[44] Additional explanations for the opposition against the development, is that workers do not want their performance to be visualized and tracked.[45]

When it comes to the degree of competence among the employees that is needed for the transformation, positive voices express that LKAB has well-educated personnel. There is extensive experience of automation and a great deal of creativity, problem-solving skills and development ambitions.[46] The competence regarding IT and digital technologies is often a question of which generation the employee belongs to. It is explained that the younger generation often learn faster mainly because they have been brought up with IT and digital technologies to another extent[47]. Nevertheless, it is also a matter of interest. Independent of which generations the employee belongs to, there are always people who are tech-savvy and people who are not. This entails that the employees often help each other, both within and between units.[48]

For some occasions, when a new technology is implemented, support from IT is provided. Partly in the form of education and training before implementation or during a testing phase but also as direct support via phone when help is needed.[49] However, there are two problems. First, it is expressed that more training and courses should be done on education about new IT-systems to employees in production, but the same person also emphasize the lack of resources to do this[50]. Second, employees in production express that the collaborative gap between IT and operations can sometimes be too big because IT-personnel tend to lack in knowledge of the point at issue in production and rely on technology to solve things. The whole collaboration is facilitated when IT-employees has worked in the production at some point of time to understand what is realistic to do or not[51]. Furthermore, the IT-division has the ambition of working closely to the operations. This is to create connectivity with the workers in the mine, to understand their problems and focus on solving the most critical problems at first.[52]

4.2.4.2 Description of the LHD

The LHD, shown in Figure 42, is a vital resource throughout the whole production loading process. It enables the sequence of activities from loading a bucket of ore, hauling and dump it into an ore pass. (Education Material LKAB, 2011) There are both manual and semi-automatic LHDs in the existing fleet. All activities are done by an operator in the machine for the manual ones. For the semi-automatic ones, loading the bucket is done remotely by an operator, then hauling and dumping is done automatically. There are both diesel-powered and electrically powered by cable, manual LHDs and the semi-automatic ones are all diesel-powered.[53] Further differences between the LHDs are as follows and are summarised at the end of the section, in Table 1.

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[44] Production Manager 1 at LKAB, Interview 23rd March 2021.
[45] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[46] Research Engineer at LKAB, Interview 5th March 2021.
[47] Operator at LKAB, Interview 23rd March 2021.
[48] Production Manager 1 at LKAB, Interview 23rd March 2021.
[49] Mine planning Engineer at LKAB, Interview 10th March 2021; Production Manager 1 at LKAB, Interview 23rd March 2021.
[50] Mine planner and layout Mine planning Engineer at LKAB, Interview 10th March 2021; Production Manager 1 at LKAB, Interview 23rd March 2021.
[51] Production Manager 1 at LKAB, Interview 23rd March 2021; Production Manager 2 at LKAB, Interview 23rd March 2021.
[52] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[53] Production Manager 1 at LKAB, Interview 23rd March 2021.

Figure 42. Shows an LHD with its bucket loaded with ore. (Education Material LKAB, 2011)

When a blast is performed, the presence of toxic gases prevents humans from entering the area in the coming hours. However, the semi-automatic ones are operated remotely, thus eliminating the problem and enabling production when toxic gases are present, resulting in more planned production hours during the day.[54] Further, fewer human resources are needed since one operator can monitor 3-4 semi-automatic LHDs, as opposed to the one driver that is required per manual LHD[55]. Additionally, the manual LHDs are idle when operators are switched after a work-shift, which is not the case for the semi-automatic ones. Besides the benefits related to utilisation and productivity, the semi-automatic LHDs bring benefits related to safety and working environment. They are operated in isolated areas where no humans are present, which decreases the risks of work-related injuries on-site. Furthermore, the office working environment from where remote operators work is expressed to be more comfortable than sitting in the machine.[56]

Apart from the benefits of semi-automatic LHDs, they also entail some challenging setbacks. First, there is the underlying problem of dependence between systems in a partly or entirely automated machine. In the case of the semi-automatic LHDs, the sub-systems are connected in such a way that it can only operate if all subsystems are functional. A setback in flexibility that leaves a benefit for manual LHDs.[57]

Second, the automated transport can only happen within an isolated production area where it is forbidden for humans and other vehicles to enter. This is surveyed right now in a way that all production stops within the area whenever a gate is opened at the entrance of the isolated area. Consequently, all LHD activities in the entire area need to be stopped when maintenance or reparation is to be done. However, in areas where manual machines are operated, production can continue in parts of the area that is not affected by the maintenance work. This results in a setback for the semi-automatic LHDs that in turn affects productivity and the intended purpose of automated LHDs being higher utilisation of the machines.[58] A solution is desired for "mix-traffic" to be feasible to a larger extent. An advanced real-time location system has been discussed that locates human employee's proximity to the machines through tracking the employees by their

[54] Research Engineer at LKAB, Interview 5th March 2021; Production Manager 1 at LKAB, Interview 23rd March 2021.
[55] Research Engineer at LKAB, Interview 5th March 2021.
[56] Production Manager 1 at LKAB, Interview 23rd March 2021.
[57] Research Engineer at LKAB, Interview 5th March 2021.
[58] Research Engineer at LKAB, Interview 5th March 2021; Production Manager 2 at LKAB, Interview 23rd March 2021.

personal tags. This technology has been proven to be expensive and hard to implement.[59] Another possible solution is to automate support functions as well, e.g., road-maintaining. This would decrease human involvement in the isolated areas.[60]

Third, all LHD systems are connected to an overlying IT system registering data such as location and bucket weight. However, the LHD systems are not integrated with each other, meaning, different LHDs cannot talk to each other. Neither are they integrated to other machines in the production loading.[61] This is illustrated in Figure 43. Consequently, communication between machines complicates the operations in the automated production area when unforeseen events take place in the daily operations. For example, in the activity of dumping into an ore pass. If the ore pass breaks, the semi-automatic LHDs cannot load onto a truck, nor can it communicate with a mobile rock breaker if the ordinary one is out of function. These activities require human communication and coordination.[62] Another problem related to communication is that LKAB's machines are from different vendors. The machines therefore have different computer hardware, software products and network services. This complicates the automation since the different systems are not communicating with each I.e., they are not interoperable. What makes it even more complex is that the incentive for the different machines to communicate is counteracted by the vendors since they are not keen to share their data. This issue is referred to as the multi-vendor problem. There are currently projects in progress aimed to fix this problem, and pilot-tests have been successfully launched.[63]

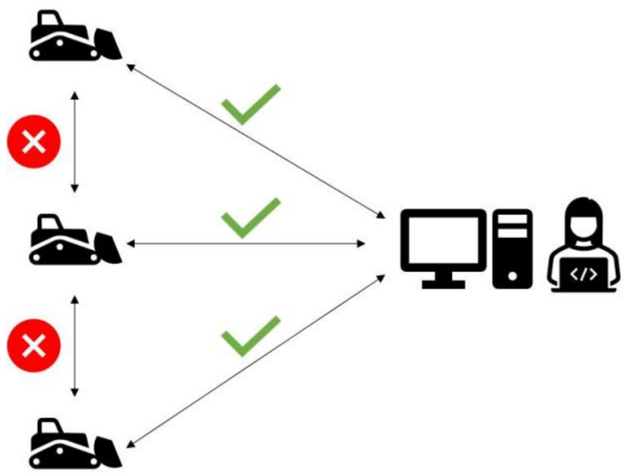

Figure 43. Illustration of how the fleet of LHDs are integrated to the overall IT system, but not yet integrated to each other.

Fourth and last, due to the absence of a human driver in the semi-automatic LHDs, they tend to wear more. In the manual machines, a driver can feel, hear and see things that possibly can harm the machine. For example, they can feel if the wheels are spinning in a gravel pit or if the LHD runs over a stone, hear if there are any strange mechanical clanking sounds and see if there are any oil leakages or punctures. The absence of a human driver in the machine leads to the inability of

[59] Research Engineer at LKAB, Interview 5th March 2021.
[60] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[61] Mine planning Engineer at LKAB, Interview 10th March 2021.
[62] Production Manager 1 at LKAB, Interview 23rd March 2021.
[63] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.

identifying problems and taking preventive measures to hinder LHD damage. This leads to more wearing of the machines and more maintenance.[64]

Table 1. Summaries the differences of manual and semi-automatic LHDs.

	Manual LHD	**Semi-automatic LHD**
Fuel	Diesel or electric cable	Diesel
Activities performed	Loading, hauling and dumping performed manually by an operator from within the LHD.	Loading is performed manually and remotely by an operator, while hauling and dumping is performed automatically.
Main benefits	- Independence between associated sub-systems. Functional despite error in one sub-system. - Can operate despite other activities performed by employees in the same area. - Operators can manually coordinate some tasks with other machines. - Operators can identify issues related to maintenance during the shift which entails less wearing.	- Operable in the presence of toxic gases after blasting. - Multiple LHDs can be monitored simultaneously by one operator. - No idle time required due to change of work-shift. - More pleasant working environment for the operator.
Main drawbacks	- Idle when changing work-shifts - Cannot be operated in the present of toxic gases - Working environment is noisy, bumpy and can be more dangerous due to seismic activity, fires, etc.	- Dependence between associated sub-systems. Non-functional in the event of sub-system breakdown. - Requires isolated areas while operating. - Production cannot continue in case of personnel nearby, e.g., for maintenance or reparations etc. - Cannot communicate and coordinate tasks with other machines. - No continuous status-check on the machine which entails more wearing.

4.2.4.4 Descriptions of media

Media, meaning the communication devices or tools that are used to store and deliver information or data, is especially important in an underground mine where one cannot rely on traditional solutions. Aggravating circumstances include seismic activity, water flow and walls of thick rock. It is hard to know where and how to place the media infrastructure most efficiently since the characteristics of the rock is changing.[65]

4.2.5 Description of the information that supports or control the activities

Information relates to what is used to support or control the activities. For the process investigated, the production loading, the support and control systems have been divided into 6 major categories each represented in one of the following sections.

4.2.5.1 IT-systems in usage

The IT-systems used today are GIRON and WOLIS. GIRON is a data management system with some features of an ERP-system, e.g., decision support such as dynamic loading. GIRON stores data such as the bucket weight and LHD locations. It has been described that all the data collected

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64 Production Manager 1 at LKAB, Interview 23rd March 2021; Production Manager 2 at LKAB, Interview 23rd March 2021.

65 Research Engineer at LKAB, Interview 5th March 2021.

in GIRON is used for analysing the performance. However, there is data not collected yet that are in development, i.e., volume of the rock loaded in the bucket.[66]

As for now, LKAB is amid a transfer from an old version of GIRON to a new one based on cloud computing[67]. The new version will support modules of cloud-based services and enable analytics to be performed in the cloud. As opposed to looking at the amount of extracted tonnage as the only indicator, these services will make it easier to correlate data collection from the production to economic performance indicators. These performance indicators are then meant to be shared to all connected devices throughout the company.[68] An example of a cloud-based service is Power BI, a Microsoft business intelligence system, that is tested and used within the mine planning. Power BI is used to analyze and visualize collected data as support for the mine planning division.[69]

In addition to GIRON, WOLIS is used to collect and show data. WOLIS is shown in Figure 44 and shows information for ring location (1), last bucket weight (2), ring design (3), extraction ratio (4), system status (5), report status (6), loading graph (7), nearby charged holes (8), ring information (9), and extraction ratio of proximate rings (10). (Shekhar, 2020).

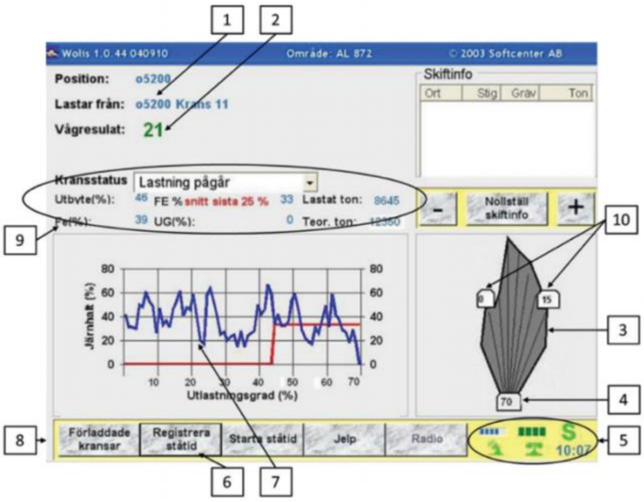

Figure 44. Showing the WOLIS window, available for the operator in their LHD. (Shekhar, 2020)

4.2.5.2 Coordinated planning and information exchange between divisions

As discussed in section 4.2.1 Description of sub-process *plan and inform where to load*, coordinated planning between different divisions is not performed optimal[70]. The lack of coordination results in idle time for the LHDs that in turn leads to productivity losses. The problem discussed originates in the planning phase and has the most severe effects in production.[71]

During the loading procedure, the operator can run into a problem that forces he or she to stop and call for maintenance. If this occurs, it is said that it would be beneficial if the maintenance that might be planned for later that day, is notified and can perform its improvement simultaneously

[66] Mine planning Engineer at LKAB, Interview 10th March 2021.
[67] Mine planning Engineer at LKAB, Interview 10th March 2021.
[68] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[69] Mine planning Engineer at LKAB, Interview 10th March 2021.
[70] Mine planner and layout specialist at LKAB, Interview 8th March 2021; Operator at LKAB, Interview 23rd March 2021.
[71] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

to decrease the total idle time.[72] However, recent tests have proven simultaneous maintenance to be difficult due to the different teams being in each other's way[73]. Although, there are potential for simultaneous maintenance if it is performed in different parts of the area[74].

4.2.5.3 Flow of information

In the daily operations, there is a constant flow of information between the *LHD operators*, *the mine control* and the *support functions* e.g., rock breaking, renovations and maintenance. Historically, the communication between these divisions has been relying on phone calls which has led to a troublesome position for the mine control in being an intermediator with a lot of duplication. A typical example was that an operator reported a problem to the mine control. The mine control then prioritized the problem among others and sent out an error report to maintenance. Many times, maintenance had to call mine control with further questions until the job was done. When the job was done, mine control had to contact the operator and update the status on the work.[75] On some occasions, the communication process still looks like this, but it is being worked away by the implementation of an information system.[76]

Today, GIRON, the data management system, is used for receiving orders from operators. E.g., an order for a big rock to be blasted in a certain ore-pass. This order is prioritized by the mine control and sent out to the unit responsible for rock breaking via GIRON. Meanwhile, the LHD operator can follow the status of the supporting work in an app, visualizing if it is ordered, booked, read, started or fixed. Since operators themselves can check the status of the supporting work, the mine control does not need to mediate the information between operators and maintenance. (Observation notes, observation 1) The problem with this system is still for the different maintenance work to be synced with the production[77]. However, not all flow of information goes through GIRON. For certain high risk, high priority tasks like renovation in an ore pass, an email of the report is sent from the responsible division, and it is printed and pinpointed on a wall in the mine control room. (Observation notes, observation 1)

4.2.5.4 Location tracking and communication

Especially in the mine, it is hard to track the location of employees and assets and ensure a perfect connection to Wi-Fi. Due to the seismic activity, it is hard to place the infrastructure of a tracking system in the mine. The movement of the bedrock might cause damage to equipment serving as measuring points. Further, there is water in the mine, creating additional complexity when compared to a traditional manufacturing industry. Despite the complexity, it has been easier to justify the development in location tracking and communication last years since the price of RFID equipment has decreased.[78]

RFID technology is currently used for both tracking and communication with employees and LHDs. There are RFID tags and readers placed in the production area as illustrated in Figure 45. These tags and readers communicate with the LHD which tunnel and ring that has been loaded, and which ore pass that is used for dumping the ore.[79] The tags are also used to track the location

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[72] Operator at LKAB, Interview 23rd March 2021.
[73] Production Manager 2 at LKAB, Interview 23rd March 2021.
[74] Production Manager 1 at LKAB, Interview 23rd March 2021.
[75] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[76] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[77] Production Manager 1 at LKAB, Interview 23rd March 2021; Production Manager 2 at LKAB, Interview 23rd March 2021.
[78] Research Engineer at LKAB, Interview 5th March 2021.
[79] Mine planner and layout specialist at LKAB, Interview 8th March 2021.

of the machine and the location is visualized in a real time 3D environment in a computer system called Mobilaris (Observation notes, observation 1). The tracking and recording of the LHDs is also thought to improve productivity by optimizing the planning and follow-up from analysing the utilisation of the LHDs[80]. One work in progress is the implementation of a transport management system that partly will optimize tramming routes for the LHDs[81]. Lastly, if the locating accuracy is improved, it can be a major step towards running the semi-automatic LHD's in the presence of maintenance workers or similar. The productivity loss due to interruptions of renovations, maintenance etc. is one of the major drawbacks for semi-automatic LHD's.[82]

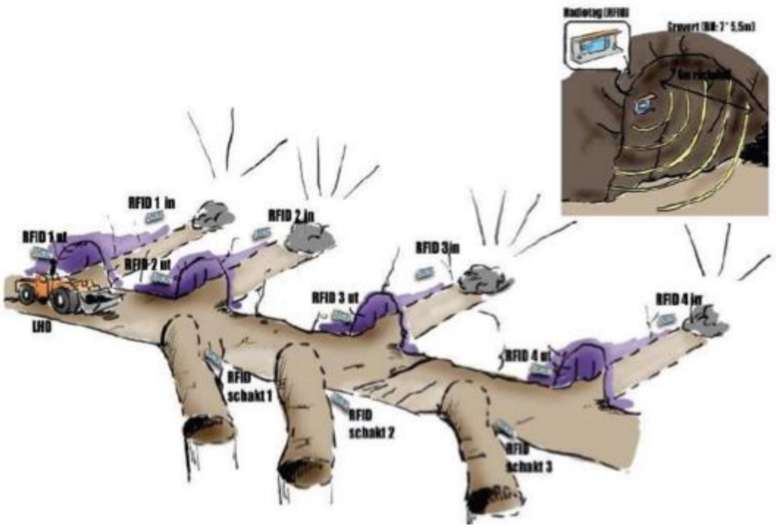

Figure 45. Illustration of the RFID tags and readers placed in the mine to communicate and share information of the production process.[83]

For tracking employees, each person has their personal tag that signals information about their location. The purpose of locating employees in the mine is mainly due to safety reasons. In the case of a fire, seismic activity or another dangerous situation, the mine control locates which employees that are in the exposed area. Then they print out a list with every employee's name and confirm via phone whether they are put in a rescue chamber or not. A new solution is in progress where the concerned employees get a notification in an app on their phone in case some dangerous situation occurs. The employee can then confirm that he or she is in a rescue chamber through the app, replacing the time-consuming way of checking each employee off a list. (Observation notes, observation 1).

In addition, tracking employees and machines can have a positive impact on productivity. Before operators can start production loading, they must drive through the drift to ensure employees are not present. Further, the gate is closed and the number-tag for the vehicle is put on the gate to signal production loading is performed. This is all manual work that could be automated with more accurate location tracking systems with screens showing the information instead.[84] There have been tests to implement such a solution, which was abandoned due to the screens showing

[80] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[81] Research Engineer at LKAB, Interview 5th March 2021.
[82] Research Engineer at LKAB, Interview 5th March 2021.
[83] Mine planning Engineer at LKAB, Interview 10th March 2021.
[84] Operator at LKAB, Interview 23rd March 2021.

incorrect information in some cases. This was because the Wi-Fi connection was not good enough.[85]

Today, communication to operators is done mainly through phone calls either via the employee's normal work phone or more likely via a special phone with greater range (Observation notes, observation 1). The problem with communication via normal work phones is the poor quality of the Wi-Fi in the tunnels. For operators, if they need to get in contact, they have the possibility to drive the LHD to a location where the Wi-Fi connection is sufficient. But if anyone wants to get into contact with the operators, sufficient Wi-Fi is always needed, which is not the case today. Instead, the specific phone with greater range is used to a greater extent.[86]

4.2.5.5 Data collection for continuous improvement

Solutions for collecting data and using it for analysis is a wide project and LKAB is investigating different approaches and cloud-based business intelligence systems that can be used, e.g., OptiMine, Deswik, Mobilaris and Power BI.[87]

Location data for tracking employees and assets are done digitally with RFID technology. Beyond location information, data is also collected from the production for different purposes such as production planning and maintenance. The bucket weight is collected digitally and automatically. The bucket weight data is then registered in GIRON where an interface is available for reports and analysis, i.e., dynamic loading.[88]

The data collected manually by the operators are deviations such as road maintenance, big rocks or rockfall, water on the roads and non-planned maintenance. The information collected serves as a basis for measurement and further analysis of reasons for certain cycle times, extraction rates, payloads, downtimes, LHD availabilities and interferences in the production.[89] However, since the data is filled manually, it is more time-consuming and harder to review[90].

For semi-automatic LHDs, additional data of driving routes can be recorded through the navigation system with the aid of sensors placed on the machine. The driving distance is one of several important factors that can be analysed to improve cycle times. Another difference is that the information manually collected is more likely to pass by unmarked due to the absence of a human operator at site.[91]

Status on the machines

By analysing the status of the LHD, meaning if the machine is idle or active, follow-up on productivity and continuous improvement is facilitated. With the information of the machine being idle or running, one can analyse data from the operators or automatically collected data, e.g., temperature or pressure at different parts of the LHD, to understand the cause of the disruption and idle time.[92]

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[85] Production Manager 2 at LKAB, Interview 23rd March 2021.
[86] Production Manager 2 at LKAB, Interview 23rd March 2021.
[87] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021; Mine planner and layout specialist at LKAB, Interview 8th March 2021; Mine planning Engineer at LKAB, Interview 10th March 2021.
[88] Mine planning Engineer at LKAB, Interview 10th March 2021.
[89] Research Engineer at LKAB, Interview 5th March 2021.
[90] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[91] Research Engineer at LKAB, Interview 5th March 2021.
[92] Research Engineer at LKAB, Interview 5th March 2021.

Today, the status of the machine is not monitored automatically for the manual LHDs. The machine is registered inactive if it has not been dumping ore during the last 15 minutes, first then, the operator has the *option* to enter a comment on the cause of not running.[93] Therefore, work that does not force the machine to be still goes by unnoticed unless operator is observant and reports it manually[94], e.g., road maintenance, rock breaker or various planned maintenance activities.[95]

Mine planners express the desire for a software that identifies automatically if the LHD is running, being still or being idle, and forces the operator to fill in the cause. This to improve planning and follow-up resulting in improved productivity with better utilisation of the LHD's.[96]

Another problem thought to be fixed with a more accurate machine-status system is to identify problems that as of today goes beneath the radar. If there is a problem with an ore pass, a ring or maintenance in some area of the drift – an operator can simply choose the load from another location until the problem is fixed. Today, this kind of problem is often unseen for the planners. Since they are not able to collect data and visualize the time spent on malfunctions, there exists an uncertainty of operations running as productive as possible.[97] Further, it is stated that the most important data to be collected is the availability of the LHD, to realize and avoid common errors.[98]

Predictive maintenance
Additionally, maintenance can be improved with the help of data collection to predict the breakdowns and decrease the rate of emergency repairs. The LHD's come in for maintenance every 6 weeks. Although, since no data of whether the LHD has been operated or not exists, sometimes time is spent on maintaining a machine that has almost not been used. It becomes clear that this redundant maintenance could be avoided if data on LHD activity during that 6-week period was collected. Predictive maintenance is divided into three levels. First level is calendar-based maintenance, second level is where machines are maintained with respects to measured values of utilisation and way of usage. The third and last step is that the machines themselves report when maintenance is needed. This third step is especially important when the loaders are automated since then there is no operator nearby to hear if there are any errors.[99]

However, it is quite a challenge to collect the machine data since the LHDs used by LKAB are purchased from different vendors and each vendor equips their machine with different technology and have different standards for sharing data.[100] It becomes a matter of interoperability where data from different LHD networks should be integrated with the interface of LKAB's IT system. (Observation notes, observation 1)

4.2.5.6 Visualization and illustration of data and decision support

Operators are to a great extent measured upon the tonnage extracted. Often operators are honoured if the extracted tonnage during the shift is high. This creates the wrong incentives for extracting ore, since extracted tonnage is not a reflection of the performance.[101] The actual visualization of an operator's performance to planners, managers and colleagues is thought to

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[93] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[94] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[95] Research Engineer at LKAB, Interview 5th March 2021.
[96] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[97] Mine planner and layout specialist at LKAB, Interview 8th March 2021.
[98] Research Engineer at LKAB, Interview 5th March 2021.
[99] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[100] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[101] Production Manager 1 at LKAB, Interview 23rd March 2021.

create an incentive for the workers to improve their work, resulting in enhanced productivity.[102] However, it is important for this measure to be based on the right criteria, which it is not as of today.[103]

An example is that some rings are more complicated than others, resulting in a low number of planned tonnages for extraction. These rings are sometimes therefore avoided by operators who instead prioritize the rings with more planned tonnages for extraction. This to maximize the tonnage extracted during the shift, which looks good on paper. All in all, this calls for a system that visualizes if the plan is followed to straighten out questions like: "Even if the production target is met, are we loading at the right place?". Furthermore, the visualization needs to be accessible for the whole organization so that fewer questions need to be asked regarding why loading is performed at a specific place at the time. This would facilitate the explanation mine planners need to do to their bosses if the production target at the time is not met.[104]

Further, operators have expressed that the different data systems are fragmented which makes it less accessible to fully utilise the support systems. E.g., the operator has one mobile phone, one screen for data illustrations and production information on the ring, one screen for the weighing of the bucket and another special phone. This can be seen in Figure 46. All in all, it is a lot to keep an eye at and therefore an integrated screen, visualizing all information, is wished for.[105]

Figure 46. Showing the cabin in a LHD with all screens. (Education Material LKAB, 2011)

[102] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[103] Production Manager 1 at LKAB, Interview 23rd March 2021.
[104] Cybersecurity and Enterprise Specialist at LKAB, Interview 8th March 2021.
[105] Operator at LKAB, Interview 23rd March 2021.

4.3 Digital Readiness and IMPULS

This section aims to present the respondents' answers in the questionnaire for evaluating LKAB's digital readiness using the IMPULS model. Each dimension is covered with the answers for each respondent. An explanation of each field is to be found in Appendix A and the questionnaire at its full extent is to be found in Appendix B. The questions were thought to focus on the production loading process exclusively. However, this was not clarified to the respondents, why some of the respondents are likely to have answered with a perspective of LKAB as an organization. Regardless of that, most of the answers are applicable to the production loading.

4.3.1 Result for each of the dimensions

4.3.1.1 Smart Factory

The result from the questions related to answering the digital readiness of smart factory is shown in Diagram 1. As can be seen, the result varies from level 1-5. However, the median is between level 2 and level 4, and the average result of all answers related to the dimension is at 3.1.

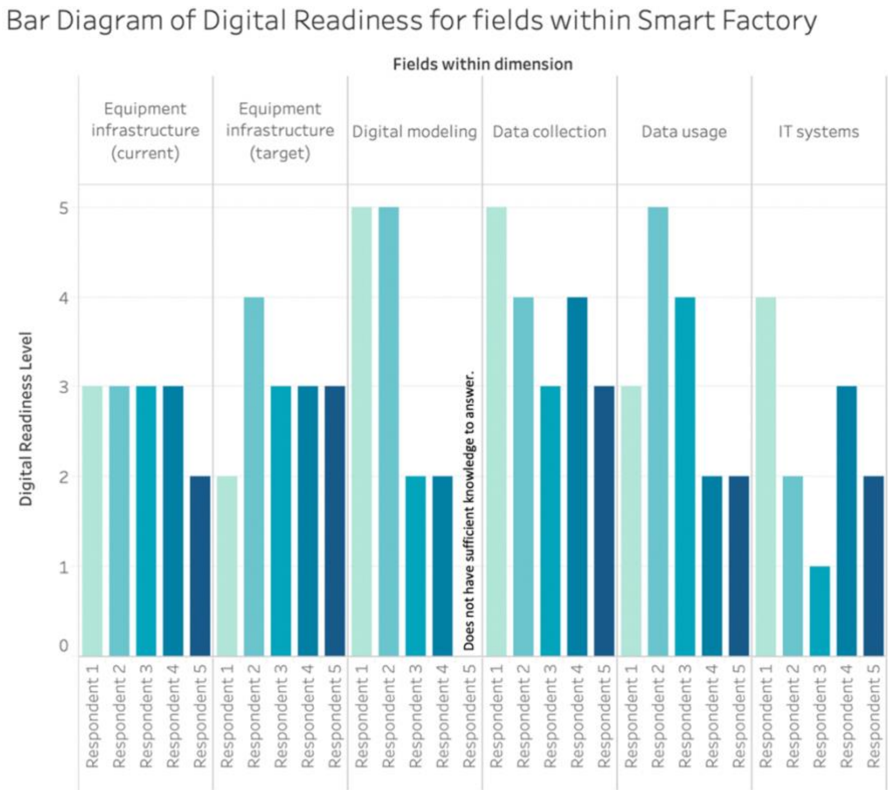

Diagram 1. Bar diagram showing the answers to the questionnaire for assessing digital readiness for each field within Smart Factory.

Question to reflect on the main challenges associated with the implementation of the smart factory resulted in the following answers:

> *"The company needs to increase its internal IT capability. We also need to show the dollar value of using digital products."*

> *"Wi-Fi coverage underground and the constant expansion of it."*

> *"Many small processes that must work together and that we really must understand for ourselves what type of data we need to see."*

> *"Automating just about all processes (even completely manual ones) is difficult. Usually requires that the process be mechanized first, which may require radical process changes."*

Summary of responses to each field within Smart Factory

The level of current equipment infrastructure is varying between level 2 to level 3. Comments related to the question elaborates that *"individual equipment systems are connected with IT, but the entire fleet is not optimally integrated"* and that *"some important processes can be completely controlled by IT but the range of processes at LKAB results in the degree of automation varies a lot"*. Further, respondent comments *"It is different depending on the business part. Mine has more decoupled operations, while a pellet plant requires that everything on the 'red' line must work, otherwise the entire function stops"* and *"An Autonomous LHD can be controlled by IT and integrates with a production area"*.

The level of target equipment infrastructure is varying between level 2 to level 4. Comments related to the question elaborates that *"all our machines and systems can be upgraded, and the vision should be to reduce the human factor in data transfer as much as possible"* and *"Most machines and systems can be developed in some sense, the potential for improvement varies depending on the process in question"*. Another comment clarifies *"The answer is for machines in our mines, for example LHDs"*.

The level for digital modelling varies between level 2 and level 5, described as *"some digital modelling"* and *"complete digital modelling"*. The question related to digital modelling only gives the option to answer between none, some or complete digital modelling. Respondent 5 has answered *"does not have sufficient knowledge to give answers"*. Comments related to the field clarifies *"Layout for Mining Planning takes place in CAD (Deswik)"* and *"We build all facilities in 3D, but in production the 3D models are not used."* Additionally, respondents answered *"We use mine planning software, Power BI and other automated systems to model certain behaviour. But we are still not completely integrated"* and that "*We use CAE daily in the planning work, in calculations and simulations"*.

The field data collection is varying between level 3 and level 5. Comments related to the question elaborates that *"we still have a lot of manual handling of production data that is collected manually"* and that:

> *"We collect information from all parts of our production, primarily for production follow-up. Work is in progress to collect more data from asset ex status and sensor data from loaders of the type of the machine stands, runs the machine, pressure, temperatures, etc."*

Data usage varies between level 2 and level 5. Comment related to the field states data usage is *"Different in different parts of the business"* and that *"To us, we use data to make the planning as good as possible."*

The last field within the smart factory dimension is IT-systems. IT-systems vary between level 1 and level 4. Comments related to the question elaborates that *"the most important processes are automated and integrated"* and that *"IT is used for all processes but is not fully integrated in all parts of the business"*.

4.3.1.2 Smart Operations

The result from the questions related to answering the digital readiness of smart operations is shown in Diagram 2. As can be seen, the result varies from level 2-5. However, the median is between level 3 and level 5, and the average result of all answers related to the dimension is at 4.3.

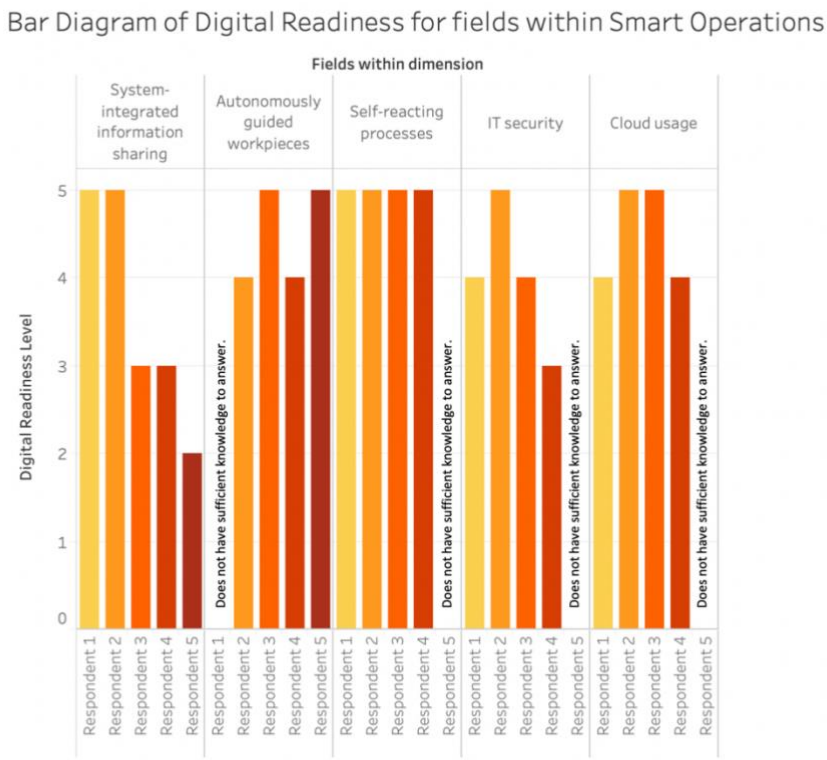

Diagram 2. Bar diagram showing the answers to the questionnaire for assessing digital readiness for each field within Smart Operations.

Main challenges associated with the implementation of the smart operations were stated to be *"smooth interoperability of the different systems"*, *"inertia in making data accessible"* and *"everyone talks about it, but few know what is required"*.

Summary of responses to each field within Smart Operations

The level of system-integrated information sharing is varying between level 2 and level 5. A comment from a respondent is *"We have multiple external partners with which we successfully share information"*.

The field of autonomously guided workpieces varies between level 4 and level 5, described as being between *the tests and pilot phase* and *the usage phase* of autonomously guided workpieces. One respondent has comments that *"I do not understand what is meant by "workpieces""*, another respondent has expressed *"We use autonomous drilling rigs, loaders (LHD), trains and skippers"* and lastly *"We are trying different levels of automation in production and in planning process"*.

Self-reacting processes are placed at level 5, described as "*used in selected areas or even cross-enterprise"*. One of the respondents has answered that *"I do not understand what is meant by "Self-regulating processes""*. Another commented *"most control systems have a control model built in that provides "self-regulation" between actual and setpoint values"*.

IT security varies between level 3 and level 5. No comments were left related to the field.

The level of cloud usage is between level 4 and level 5, described as somewhere between *initial* and *multiple solutions implemented*. A comment on the field is *"we use cloud solutions to a limited extent today, but within 2 years we will have extensive cloud solutions"*.

4.3.1.3 Smart Products

The result from the questions related to answering the digital readiness of smart products is shown in Diagram 3. As can be seen, the result varies from level 2-5. However, the median is at level 3 for both questions as well as the average result of all answers related to the dimension.

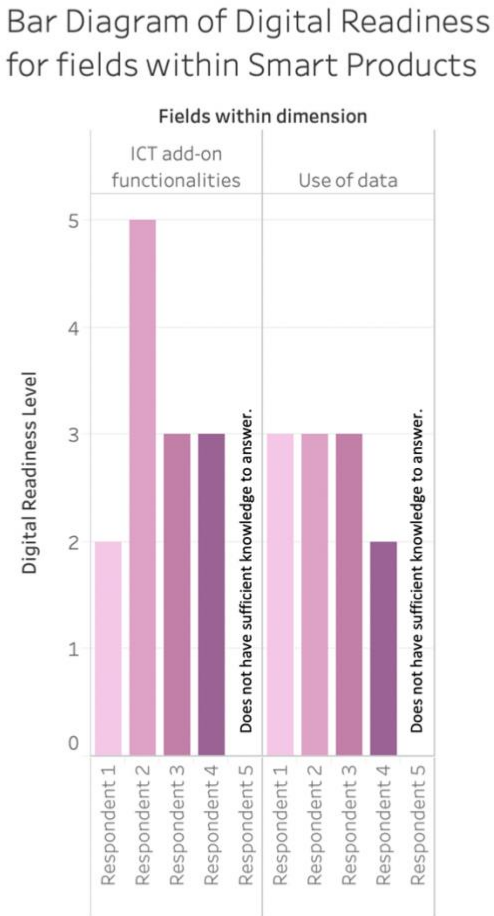

Diagram 3. Bar diagram showing the answers to the questionnaire for assessing digital readiness for each field within Smart Products.

Summary of responses to each field within Smart Products

ICT add-on functionalities vary between level 2 and level 5. Respondents' comments shows that respondents have interpreted the question differently:

> *"If you mean machines and equipment used in the manufacture of the products, this is used to a large extent."*

> *"Here we are dependent on the suppliers and what they equip their machines with. There are also so many standards in this area that it is difficult to scale. We also have a large part of our business underground, which does not make it easier."*

> *"In each location there is an RFID tag that tells the loader which location and ring is loaded and to which shaft, we also have RFID tags on our trucks in the truck loop as a safety aspect for the truck to be in position before you start dropping."*

The use of data is varying between level 2 and level 3. Level 3 is described simply as *"data is analysed/used"*. This was the highest level possible to achieve for this field, meaning level 4 and level 5 was not an option.

4.3.1.4 Employees

Employees consist of only one field describing the employee's skills. The dimension has an average result of 3.4 and the median of value 3. The answers vary between level 2 and level 5. The result for each field is shown in Diagram 4.

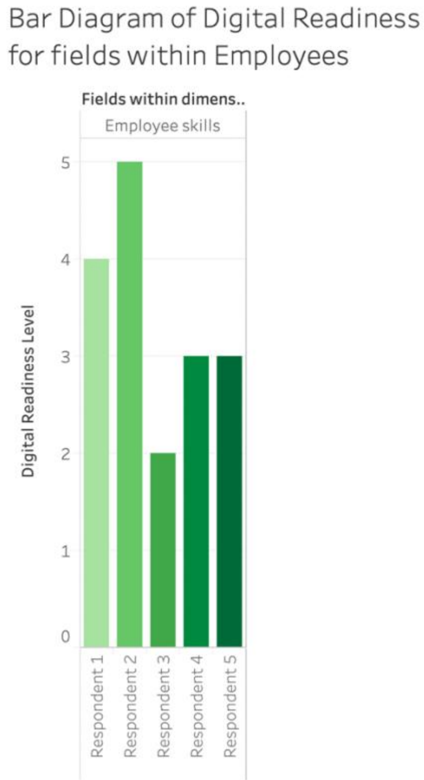

Diagram 4. Bar diagram showing the answers to the questionnaire for assessing digital readiness for each field within Employees.

Comments related to the field are:

"Level of competence is probably varying a lot"

"Difficult question, but LKAB has for a long time required 3 years of high school education when recruiting. Where the increasing use of IT in production and also enable change of future tasks is an important parameter"

"I would say that we have a fairly low level of competence because many of our systems are outdated and we have not succeeded in developing them where we want."

4.3.2 Assessing the overall Digital Readiness

The readiness level for a dimension is determined by the lowest achieved level for a field within that particular dimension. The result of this is shown in Diagram 5.

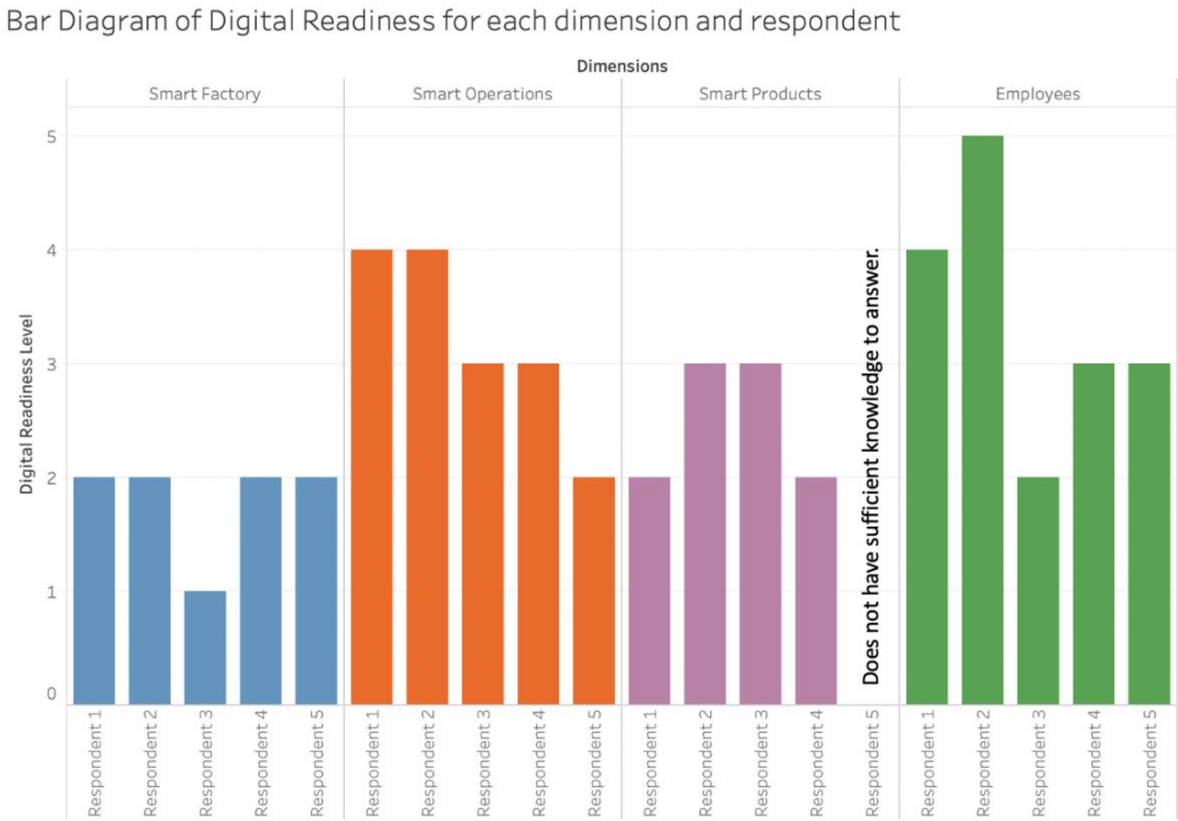

Diagram 5. Bar diagram showing the readiness level for each dimension and respondent.

Further, the overall digital readiness is assessed by using the weighted system described in section *3.4.3.3 Assessment of Digital Readiness*. The calculations, and the result, for assessing LKAB's digital readiness according to each of the respondents is shown in Table 2.

Table 2. Showing the calculations made for assessing LKAB's digital readiness according to each of the respondent's answers in the questionnaire.

	Calculations for assessing the Digital Readiness	**Assessed Digital Readiness for LKAB**
Respondent 1	$2 * 0.23 + 4 * 0.16 + 2 * 0.31 + 4 * 0.30 = 2.92$	2 – Learner
Respondent 2	$2 * 0.23 + 4 * 0.16 + 3 * 0.31 + 5 * 0.30 = 3.53$	3 – Leader
Respondent 3	$1 * 0.23 + 3 * 0.16 + 3 * 0.31 + 2 * 0.30 = 2.24$	2 – Learner
Respondent 4	$2 * 0.23 + 3 * 0.16 + 2 * 0.31 + 3 * 0.30 = 2.46$	2 – Learner
Respondent 5	$2 * 0.33 + 2 * 0.24 + 0 * 0.00 + 3 * 0.43 = 2.43$ *	2 – Learner

*The calculation for respondent 5 was modified to be weighted with the same relative importance if smart products dimension were to be excluded. This due to no digital readiness level for smart products were able to be extracted for that respondent.

5 ANALYSIS

This chapter aims for the authors to analyse and identify key objectives for LKAB going through a digital transformation based on the information and insights from value-based process modelling and the Digital Readiness model called IMPULS.

The first four sections, 5.1-5.4, cover an analysis of the different dimensions: smart factory, smart operations, smart products and employees. Each section covers a dimension and its fields. The analysis is performed for each of the fields and are divided into four parts:

- *First, the digital readiness at LKAB is assessed based on the insights from value-based process modelling (VPM), where the information is collected from interviews and observations.*
- *Second, the result from the IMPULS questionnaire is analysed.*
- *Third, a comparison between the assessed digital readiness by the authors based on value-based process modelling and the assessed digital readiness based on the IMPULS questionnaire is made.*
- *Fourth and last, each field is reflected upon with factors such as its relevance, correctness and potential improvements.*

The fifth section covers a summary of the analysis. First, a summary of the overall digital readiness and key-takeaways related to IMPULS are presented. Thereafter, the key objectives identified for LKAB to focus on in going through a digital transformation are presented.

The aim of the analysis is to get insights on the outcome of using value-based process modelling as a complement to IMPULS for identifying key objectives in going through a digital transformation. The framework for the analysis is shown in Figure 47.

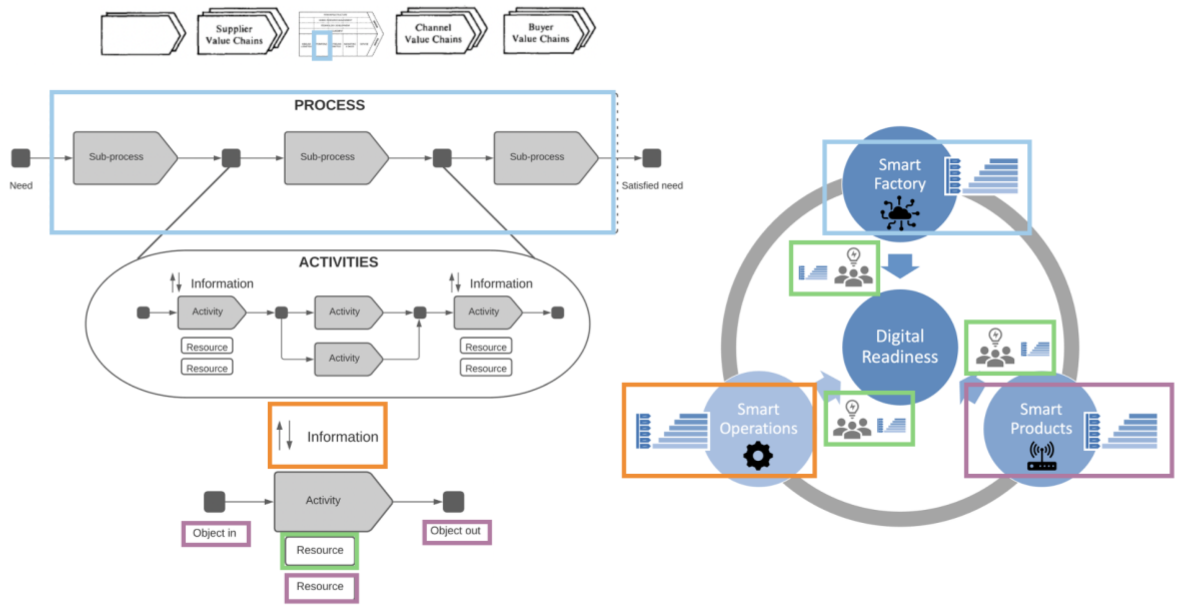

Figure 47. Illustration of the framework, i.e., using value-based process modelling (VPM) as a complement to IMPULS, thought to facilitate companies to understand how to proceed with a digital transformation.

5.1 Analysis of production processes through the perspective of Smart Factory

5.1.1 Equipment infrastructure (current)

Assessing Digital Readiness based on insights from VPM

The field investigates to what extent LKAB's equipment infrastructure enables integration and interoperability between machine and IT systems as well as how the machine systems are integrated and interoperable to each other. The levels range from an infrastructure allowing no control or integration, to full control of machines through IT and integration between machines.

The machines included in the production loading are the LHDs and the rock breakers. All LHDs have their own system based on ICT equipment that are integrated with IT-systems to communicate its location as well as product information. However, the manual LHDs are controlled by a human operator from inside the LHD and the semi-automatic LHDs are controlled through IT since the loading activity is performed remotely by an operator, whereas hauling and dumping is automatic. At last, the LHDs in production loading are not integrated machine to machine. Each LHD system communicates with the IT-system in varying degrees, but the LHD systems do not interact with each other. In addition to the LHDs, the other type of machines in the production loading are the rock breakers. The mobile rock breakers are entirely manual, the fixed rock breakers are controlled remotely by an operator. The rock-breakers are not integrated with each other and most importantly, they are not integrated with the LHDs.

Semi-automatic LHDs can be *controlled* through IT. All LHDs are *integrated* to the IT-systems. None of the LHDs allows integration between the machines nor to other machines e.g., rock breakers. Consequently, this field is on *level 2*, described as "*machine and system infrastructure can be controlled to some extent through IT, is interoperable or integrated"*. To reach level 3, expanding the range of machines that can be controlled through IT and establishing integration machine to machine is needed. This requires an upgrading that is discussed in the next field *Equipment infrastructure (target)*.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

4 out of 5 of the respondents answered that the readiness was at level 3, described as *"machine and system infrastructure can be controlled through IT and is partially integrated"*. One respondent instead answered level 2, "*machine and system infrastructure can be controlled to some extent through IT, is interoperable or integrated"***.** Comments related to the field are shown in Table 3.

Table 3. Includes the comments related to the field from the questionnaire.

Assessed level and its description	**Comment to the answer**
Level 3 - *Machine and system infrastructure can be controlled through IT and is partially integrated.*	"Some important processes can be completely controlled by IT but the range of processes at LKAB results in the degree of automation varies a lot". "individual equipment systems are connected with IT, but the entire fleet is not optimally integrated" "It is different depending on the business part. Mine has more decoupled operations, while a pellet plant requires that everything on the 'red'

	line must work, otherwise the entire function stops" "An Autonomous LHD can be controlled by IT and integrates with a production area"

The respondents had a similar understanding of the readiness for the machines and equipment. However, it becomes clear from the comments that the respondents focus on different levels of processes. Two of them discussed LHD and therefore probably answered the question from the perspective of production loading, while another two respondents have had the perspective of the entire operations at LKAB. Although the words 'integrated' and 'interoperable' were not defined to the respondents, none commented on any confusion on the words. It can be reasonable to argue that the exclusion of the definitions had an impact in the result since the word's definitions can be difficult to understand. However, no such indications were shown.

Further, as the respondents commented, some processes at LKAB can be seen as having a high degree of readiness. Still, there are machines and systems within the company that are not able to be controlled through IT, even less be integrated or interoperable.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to equipment infrastructure (current) and the assessed digital readiness based on the VPM is shown in Diagram 6.

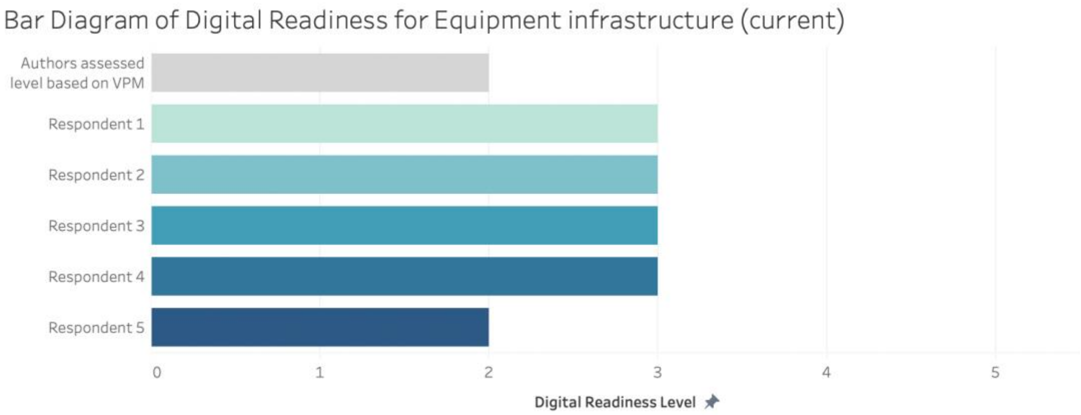

Diagram 6. Bar diagram showing the assessment of digital readiness for the field equipment infrastructure (current).

For the comparison of the authors assessment, and the one from the respondents, it can be seen that there is a slight difference. However, because of the vague formulation of the two levels, combined with the lack of a definition to the central concepts of integration and interoperability, this is not of major importance. The result shows a clear concurrence of the existence of machines and systems that are controlled by IT. The improvement of integration and interoperability is in the development phase for the machines and systems controlled by IT. However, there are still some machines and systems not controlled through IT, which might lack behind.

Reflection on the field equipment infrastructure (current)

The field is thought to be relevant for the assessment of digital readiness since the equipment infrastructure and current state is highly important for achieving Industry 4.0. This due to equipment needs to be integrated and interoperable to enable smooth upgrades and improvements in automation and information (to be discussed more in the following section). The criterion for evaluating the field is thought to be sufficient and has the potential of providing a correct result. However, due to the difficulties in understanding the concepts of integration and interoperability, the validity of the field can vary.

5.1.2 Equipment infrastructure (Target)

Assessing Digital Readiness based on insights from VPM

This field investigates whether the existing machines and systems in the production loading process can be upgraded or not. The criterion for the different levels ranges from that the machines and systems cannot be upgraded to that they already meet all future requirements.

Some systems are being upgraded in the production loading. An example is the second version of the IT system GIRON. Even if some systems are upgraded and some of the company's equipment infrastructure already meets future technical requirements, the field investigates whether the company is working on an integrated solution to enable comprehensive upgrading. The emphasis on an integrated solution for "upgrading" the entire equipment infrastructure can be interpreted as the need of having a flexible system that easily can be upgraded with new technology and is interoperable with new modules and systems without replacing the existing equipment. From this interpretation, LKAB's entire equipment infrastructure in the production loading system, meaning machines, IT, and media, need to be integrated before it can be upgraded. Which it is not as for now.

Additionally, in LKAB's goal to increase productivity by 50%, automation plays a key role. To upgrade the semi-automatic LHDs to a higher level of automation e.g., autonomous LHDs enabling the machines to take decisions on their own, the machine-to-machine communication needs to be improved. It would require an upgraded equipment infrastructure allowing integration between the machines in the production.

Therefore, the conclusion is that *some* machines and systems can be upgraded independently, resulting in this field to reach *Level 2*. To reach level 3, where *all* machines and systems can be upgraded, they first need to be integrated. An obstacle to this progress is the "multi-vendor problem". It addresses the issue that machines from different vendors have different technologies and standards and might not be interoperable with each other or the overlying IT system. In the SUM project, there are on-going experiments that aim to solve the communication between machine systems created by different vendors.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

60% of the respondents answered that the readiness was at level 3, described as *"all machines and systems can be upgraded"*. One respondent answered level 2, being that *some* machines can be upgraded. Another respondent answered level 4, described as *"machines already meet some of the requirements or can be upgraded"*. Comments related to the field are shown in Table 4.

Table 4. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 2 - *Some machines and systems can be upgraded.*	"The answer is for machines in our mines, for example LHDs."
Level 3 - *All machines and systems can be upgraded.*	"All our machines and systems can be upgraded, and the vision should be to reduce

	the human factor in data transfer as much as possible."
Level 4 - *Machines already meet some of the requirements or can be upgraded.*	"Most machines and systems can be developed in some sense, the potential for improvement varies depending on the process in question."

The criteria for each level can be seen as ambiguous. It can be interpreted that all systems and machines *can* be updated, or that they *should* be updated. From the comments, it becomes clear that the different levels may depend on how the criteria are interpreted.

The criteria for level 2 and 4 both emphasize that not all machines and systems can be upgraded even though the reason for why is different. However, these reasons are difficult to interpret if the respondents had in mind and based on the answers for the two levels, the common message is that depending on which area and which process that is in focus, *some* machines can be upgraded but not all.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to equipment infrastructure (target) and the assessed digital readiness based on the VPM is shown in Diagram 7.

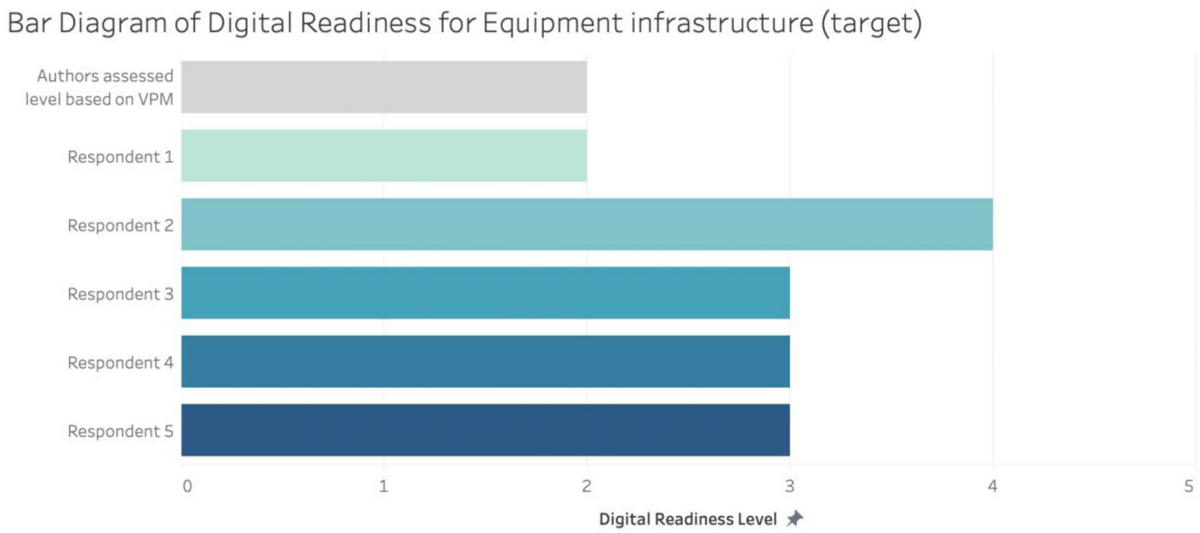

Diagram 7. Bar diagram showing the assessment of digital readiness for the field equipment infrastructure (target).

Author's assessment based on VPM resulted in level 2. The gathered data resulted in that "*some*" machines and systems can be upgraded. It was reasoned whether "*all*" machines and systems in the production loading can be upgraded or not. The conclusion was that it could not, due to the lack of integration between the machine and systems.

This results in a difference between the result from the VPM compared to the answers in the questionnaire where 60% answered that *all machines and systems can be updated*. Due to the ambiguous nature of the requirement to meet level 3, it is uncertain if the respondents meant that the equipment infrastructure *can* or *should* be updated. An interesting take-away is that the integration of the machines and systems before comprehensive updates of all machines and systems was not mentioned by the respondents. The reason can be both that it went by unmarked or that the question was misinterpreted. Nevertheless, it is important to address the issue for the production loading to achieve a state where machines and systems are controlled entirely through IT and are fully integrated.

Reflection on the field equipment infrastructure (target)
The field of targeted equipment infrastructure relies a lot on the concept of being able to be upgraded or not. The field is relevant in digital readiness to ensuring continuous improvement of machines and systems to be performed easily. However, the interpretation of if the machines and systems are able to be *upgraded* or needed to be *exchanged* are not clear. Therefore, the answers are likely to be dependent on the interpretation of the respondent. This results in poor validity of the field. It is thought that this can be improved by simply clarifying the field's criteria to discuss if the equipment can be upgraded *or* needs to be exchanged.

5.1.3 Digital Modelling

Assessing Digital Readiness based on insights from VPM
This field investigates to what extent digital modelling is used in the production loading. Digital modelling is characterised by the testing of designs or solutions to problems, through digital solutions such as CAD or simulations. The field is divided in levels of none, some and complete digital modelling possible.

The first example is the "open plan", used by the mine planners to visualise the strategy of how different areas in the mine will be loaded. It requires a digital model of the mine from where the plan is constantly updated and worked on. This digital model exists as a CAD drawing in a software called MicroStation. The CAD model is then used as decision support for what rings that should be blasted during a certain time frame. The second example is that the mine control can keep track on positions of LHDs in the mine through a software called Mobilaris. The RFID technology equipped on the LHDs enables real-time data sharing on the machine location. The location data is presented in an interface consisting of a 3D model of the mine showing locations and movement of LHDs in real-time.

The two digital models presented so far are used for planning work and visualisation. In terms of digital models used to improve the activity of performing production loading, "Dynamic loading" can be interpreted as the one example. It collects data from the production, analyses the data and produces information that serves as support for an operator to take the final decision. Besides from that, in the mine planning, some cloud-based software intended for automated analysis of the collected data in the production are in the testing phase and used to some extent.

The levels for the field of digital modelling consist of only three levels, level 0, level 2 and level 5. Due to the few examples of digital models used in the production loading, *some* digital modelling exists. Hence, the assessed level in the field is *level 2*. To reach level 5 *"complete modelling possible"*, the production loading strategy can be simulated before it is executed in real life.

Before level 5, it is more likely that some intermediate state is achieved where more digital modelling is performed. On a tactical level, there is indeed a need for a more thorough analysis to structure the strategy of choosing what rings that should be loaded and how. Instead of the current procedure substantiated by "gut-feeling" and routine. Data like the number of rings in a sequence, transportation distance from ring to ore pass, ore pass availability, rock restrictions etc. can be analysed in digital models that simulate and optimize the production setup. For this purpose, there are systems currently intended for implementation, e.g., Power BI and Optimine. The systems have already been implemented and are used to some extent in the mine planning. Although, before these systems can be useful, it is important that there is an equipment structure and information sharing system that allows for the systems to be utilised to their full potential.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model
Two of the respondents answered that the readiness was at level 2, described as *"some digital modelling"*. Additional two respondents instead answered level 5, *"complete digital modelling"*. One respondent answered he or she did not have the sufficient knowledge to provide an answer. Comments related to the field are shown in Table 5.

Table 5. Includes the comments related to the field from the questionnaire.

Assessed level and its description	**Comment to the answer**
Level 2 – *Some digital modelling.*	(1) "We use mine planning software, Power BI and other automated systems to model certain behaviour. But we are still not completely integrated." (2) "Layout for Mining Planning takes place in CAD (Deswik)"
Level 5 – *Complete digital modelling.*	(3) "We use CAE daily in the planning work, in calculations and simulations." (4) "We build all facilities in 3D, but in production the 3D models are not used."

Besides from the levels mentioned, level 0 described as *"No digital modelling"* was also an option. The reduction of possible levels to choose explains the big gap in assessed digital readiness levels.

Comments labelled (2) and (4) concerned digital 3D models but were assessed to different levels. A possible reason why they are assessed to different levels can be due to different interpretations of the extensiveness in the term digital modelling. It is likely that the respondent of comment labelled (4) interprets CAD and 3D models to be the same as digital models and therefore thinks that a complete digital model can exist if the usage is extended to the production. While the comment labelled (2) suggests that the respondent interprets CAD and 3D models as one type of many applications in digital modelling.

In addition, there are two more comments discussing the type of digital modelling concerning simulations but was also assessed to different levels. They both express that some simulations or modelling of certain behaviours exists today. However, they have different opinions on whether complete digital modelling is possible. Comment labelled (1) implies that some digital modelling exists but the way to a complete digital model is hindered by the fact that they are not yet completely integrated. Comment labelled (3) suggests that calculations and simulations exist in the daily work and thereby, complete digital modelling is possible.

Lastly, a respondent clarified the lack of complete integration. The comment is interpreted as the integration being a hurdle to master before exceeding to higher levels.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to digital modelling and the assessed digital readiness based on the VPM is shown in Diagram 8.

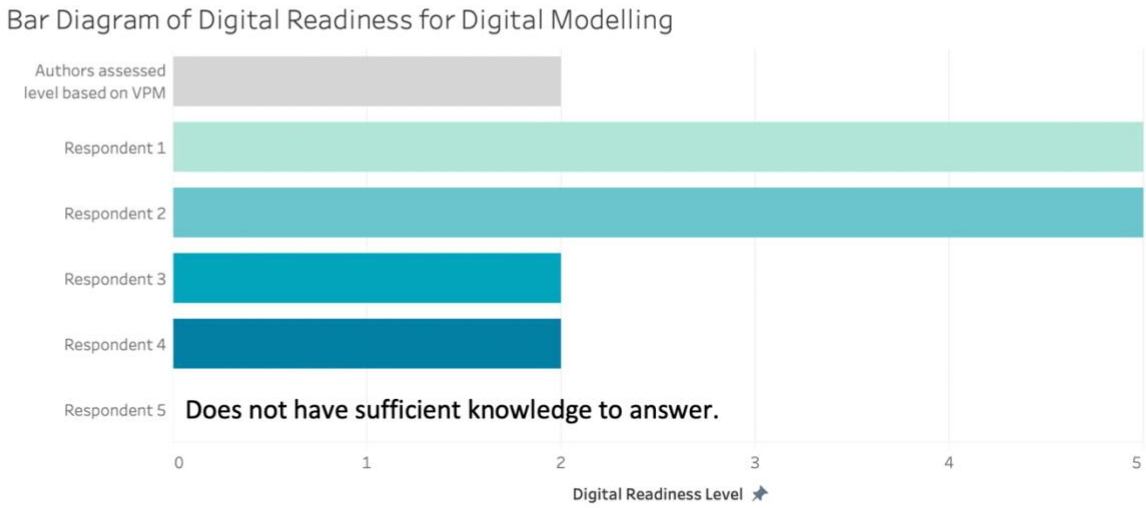

Diagram 8. Bar diagram showing the assessment of digital readiness for the field digital modelling.

As illustrated, the authors' assessment correlates with the assessment by two of the respondents. The comments from these respondents are in line with the authors' insight from process mapping. In summary, the existing digital modelling in production loading today is predominantly 3D models as support for the mine planning. For digital modelling referring to simulations to improve the process, there are some existing examples but the way towards a complete digital modelling in that sense is yet to be embarked by the implementation of new systems. A key take-away is also that the authors expressed the need of a capable equipment infrastructure to proceed with digital modelling. Which can be backed up by the respondent that emphasized on the integration of the systems to enable complete digital modelling of the production loading.

Reflection on the field digital modelling

Digital modelling is relevant for assessing digital readiness as it is seen as an important tool for analysing and using the data collected. The usage of simulations can gain improved efficiency and the visualization of a 3D facility can improve location tracking for transparencies to improve safety or productivity.

The criteria of digital modelling ranges from *none*, *some* to *full* digital modelling possible. As discussed, it is difficult to distinguish the different levels. Therefore, the criteria used for assessment is requested to be more explicit in certain levels. Both to the extent of digital modelling used, but also the actual quality of the digital modelling.

5.1.4 Data Collection

Assessing Digital Readiness based on insights from VPM

This field aims to sort out to what extent data is collected in the production loading and how it is collected. It investigates if the collection captures the most relevant data or if it is more comprehensive. It also investigates if the data is collected manually or automatic as well as analogically or digitally. *Manually* refers to a human actively collecting the data. *Automatically* means that the data collection does not require an action from a human. The data is collected *digitally* if it is collected to a computer or similar digital platform and *analogically* if it for example is logged on a sheet of paper.

On the LHDs, the bucket weight and the location of the LHD is collected automatically and digitally. In addition, the semi-automatic LHDs record the driving route as well. However, the manual data collection is predominant in production loading. Normally this is information identified by operators, an example is downtime due to disruptions such as road-maintenance or media errors. This kind of information is hard to automate, but today it is the operator's responsibility to inform the downtime and reason to the mine control. There is no system to force the operator to do so, which is why this information is thought to be limited in its accuracy. Operators also manually place orders of support functions e.g., maintenance and reparation, when they are needed in the production. This information is collected in GIRON from where mine control prioritizes and communicates the orders between different divisions.

It could be reasoned that the data collected *digitally* today is relevant data. This description matches with *level 3* stating that relevant digital data is collected in *certain* areas. However, level 2 with its description *"data is collected but for the most part manually"*, can also be argued for. Due to the most valuable and significant data being collected automatically and digitally, the conclusion is the placement of LKAB at level 3. Table 6 summarizes the digital data collected today from production loading and how it is collected.

Table 6. Summarizes the digital data collected today.

Collected data	Way of collection
LHD bucket weight	Automatically
Location of LHD (Available to mine control)	Automatically
Driving Route (Semi-Auto. LHD)	Automatically
LHD Activity (Downtimes)	Manually
Reason for downtime	Manually
Support function orders	Manually

To reach level 4, instead *comprehensive* digital data collection should be performed in *multiple* areas. To achieve this level, the accuracy of data collection should be improved, and more data collected. There is work in progress to investigate what data to be collected and how this should be made. Examples of additional data and more comprehensive data to be collected are listed in Table 7.

Table 7. Showing examples of data points aimed to be collected digitally and automatically.

Additional collected data	Way of collection
Location of LHD (Available to operators in the drifts)	Automatically
Driving Route for manual LHDs	Automatically
LHD Activity (Operational, Idle, Downtime)	Automatically
LHD Status (Abnormal values, malfunctions)	Automatically

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model
Two of the respondents answered that the readiness was at level 3, described as *"the relevant data is collected digitally in certain areas"*. Additional two respondents instead answered level 4, *"comprehensive digital data collection in multiple areas"*. One respondent answered level 5, meaning that *"comprehensive, automated, digital data is collected in all areas"*. Comments related to the field are shown in Table 8.

Table 8. Includes the comments related to the field from the questionnaire.

Assessed level and its description	**Comment to the answer**
Level 3 – *The relevant data is collected digitally in certain areas.*	"We still have a lot of manual handling of production data that is collected manually."
Level 5 – *Comprehensive, automated, digital data is collected in all areas.*	"We collect information from all parts of our production, primarily for production follow-up. Work is in progress to collect more data from asset ex status and sensor data from loaders of the type of the machine stands, runs the machine, pressure, temperatures, etc."

One respondent answering level 3 explains that even though relevant data is collected digitally, a lot of manual handling of manually collected production data still occurs. The comment underlines that level 2 and level 3 should not be seen as definite. Relevant data can be collected digitally in certain areas despite data being collected manually for the most part.

In contrast, another respondent assessed level 5 and his or her comment raises some questions on the accuracy of the assessed level. First, it is unsure if the respondent paid attention to the difference from level 4 which has the same criteria as level 5 only in the latter, data is collected automatically in each area. Secondly, the respondent commented on the work in progress of many remaining examples of data to be collected, which questions the implied comprehensive current data collection.

Consequently, it is fair to say that the assessed level from the respondents lies between level 3 and level 4. There is a consensus on the fact that data is collected digitally but a disagreement on whether it is the most relevant data in some areas or comprehensive data in multiple areas. The different answers can be a definitional matter due to the ambiguity in the levels. An example could be the point of reference. Meaning, if LKAB had a very limited amount of data collection some time ago, the reference to the current state can be interpreted as being comprehensive. Furthermore, they could be different due to different perspectives from the respondents since some refer to the entire operations and others only to production loading.

However, an important take-away is that despite the reasons stated above, 3 out of 5 respondents suggests that *comprehensive* data is collected digitally.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to data collection and the assessed digital readiness based on the VPM is shown in Diagram 9.

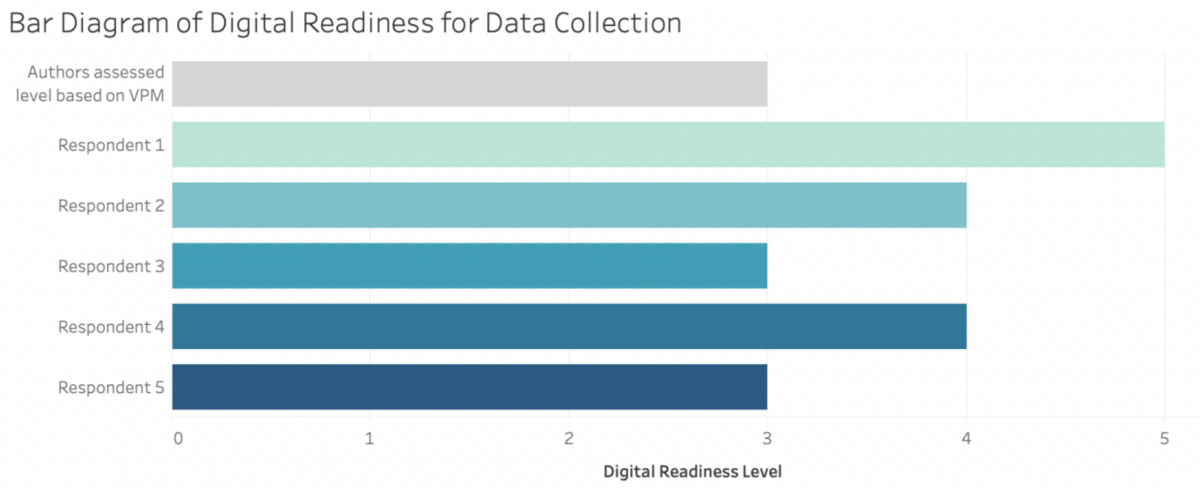

Diagram 9. Bar diagram showing the assessment of digital readiness for the field data collection.

When comparing the authors' answers from the VPM and the answers from the questionnaire, it becomes apparent that the same reasoning was behind the assessment for level 3. The comment for level 3 is somewhat aligned with the uncertainty the authors faced in the decision between choosing level 2 or level 3. With other words, the criterium of the two levels can exist at the same time.

Furthermore, two respondents assessed the same levels as the results from the VPM. The two respondents are working within the areas of mine planning or production loading. This implies that they most likely had the data collection in the production loading process in mind, similar to where the focus is put in the VPM.

An inevitable fact to address is that 3 out 5 respondents suggested that *comprehensive* data is collected digitally. During the process mapping, the authors were under the influence that some relevant data is collected digitally. However, with the many additional data collection opportunities, it becomes evident that the collection is not comprehensive.

Despite the possible misinterpretations of the levels mentioned previously, it is considered important to highlight the difference in the result from the questionnaires to the one in the VPM when it comes to *comprehensive* data collection. This supports the findings from the VPM that more data needs to be collected in the production loading to achieve a higher digital readiness.

Reflection on the field data collection

A notice on the evaluation criteria for data collection is that it is sometimes inadequate and shows misleading results, e.g., the data collection when operators manually enter data on downtimes and reasons. However, this has no effect on the level in the model. Therefore, it is thought that the field data collection does not cover the entire range of digital readiness for data collection, meaning that the validity of the field is not as good as it could be.

Further, the criteria between level 3 and level 4 are thought to be a big jump in digital readiness. Going from *"the relevant data is collected digitally in certain areas"* to *"comprehensive digital data collection in multiple areas"*. There is a big difference between *relevant data* and *comprehensive data*, which makes a level with the criteria for *some data* needed to be included for improved accuracy.

5.1.5 Data Usage

Assessing Digital Readiness based on insights from VPM

This field assesses how the collected data is used in the production loading. The field differs between if the data is used for greater transparency such as visualization and monitoring or if it is used to optimize processes.

Much of the data collected is used for process improvement and increased transparency. For transparency, i.e.., visualization and monitoring, the location of the LHD is collected for mine control to keep track of the machines. Furthermore, the system for support function orders visualizes the different on-going supporting tasks e.g., maintenance, to facilitate the communication between operators, mine control and service personnel.

The data collected to improve processes are for support rather than optimization. The LHD collects data for the decision support system called dynamic loading that supports the operator on the decision to proceed loading or close and abandon the ring. Further, there are more data that are collected from the production which are analysed by extracting and visualizing the data manually. This includes data used for follow-up to understand indicators like downtimes, complete cycles times, extraction rates, payloads and LHD utilisation.

There is work in progress to use cloud-based IT-systems for analysing and illustrating the results to gain deepened insights. Some of these systems provide analysis through AI, which will be an enabler to use data for optimization and not only support. Examples are Power BI, OptiMine and Deswik. Some of the data needed is available today, but additional data collection needs to be established for the optimising software to be utilised to its full extent.

Summarising, data is used for transparency and to support activities such as decision to stop production loading at a production site, planning or follow-up. Many times, it is raw data for the personnel to process before attaining usable information. However, there are some more sophisticated solutions such as dynamic loading. This places data usage at *level 2*, using data for a few selected purposes such as greater transparency. The collected data used for a few purposes is presented in Table 9.

Table 9. Showing the collected data and its usage.

Data collection	Way of collection	Data Usage
LHD bucket weight (Dynamic Loading)	Automatically	Decision support
Location of LHD	Automatically	Visualisation for mine control to keep track of the LHDs.
Driving Route (Semi-Auto. LHD)	Automatically	Follow-up
LHD Activity (Downtimes)	Manually	Follow-up
Reason for downtime	Manually	Follow-up
Support function orders	Manually	Visualisation for mine control to keep track of on-going support functions.

For the next level, data should be used for optimizing processes. To achieve this level, data that affects the productivity in the mine should be analysed and visualized in a way that the decision on where and how to perform production loading is a decision of fact rather than a decision of "gut-feeling". Additionally, when information of status on the machine is collected as discussed in the previous section, this can be used for maximizing running time and minimizing wear on the machines with predictive maintenance. The additional data that should be collected and its usage is summarized in Table 10.

Table 10. Showing the additional collected data and its potential usage.

Additional data collection	Way of collection	Potential Data Usage
Location of LHD (Available to operators in the drifts)	Automatically	Save time on securing drifts before production loading
Driving Route for manual LHDs	Automatically	Additional data for follow-up
LHD Activity (Operational, Idle, Downtime)	Automatically	More advanced follow-up
LHD Status (Abnormal values, malfunctions)	Automatically	More advanced follow-up by predictive maintenance

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

Two of the respondents answered that the readiness was at level 2, described as *"Data is used for a few selected purposes (greater transparency, etc)"*. The rest of the respondents answered level 3, level 4 and level 5 respectively. These levels describe that the data is used for *optimizing* to a various extent, ranging from *some* at level 3 to *comprehensive* at level 5. Comments related to the field are shown in Table 11.

Table 11. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 3 – *Some data used to optimize processes (predictive maintenance, etc.)*	"Different in different parts of the business."
Level 4 – *Data used in several areas for optimization*	"To us, we use data to make the planning as good as possible."

As can be seen in the comments, the respondent answered level 3 referred to a wider perspective than production loading, why it is not possible to get a perception on the production loading by itself. The perspective of *where* the data is used is likely to result in different answers. Some respondents, such as the operator and production managers, might have the perspective of production loading, while other respondents working cross-functional might have had the perspective of the entire operations.

The comment left from the respondent that answered level 4 refers to the usage of data to make the planning as good as possible. This brings up the definitional matter of the term "*optimization"*. Except for the one respondent commenting on level 4. There are no other comments left on how data is used for optimization. This complicates the understanding of how the respondents interpreted the criteria.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to data usage and the assessed digital readiness based on the VPM is shown in Diagram 10.

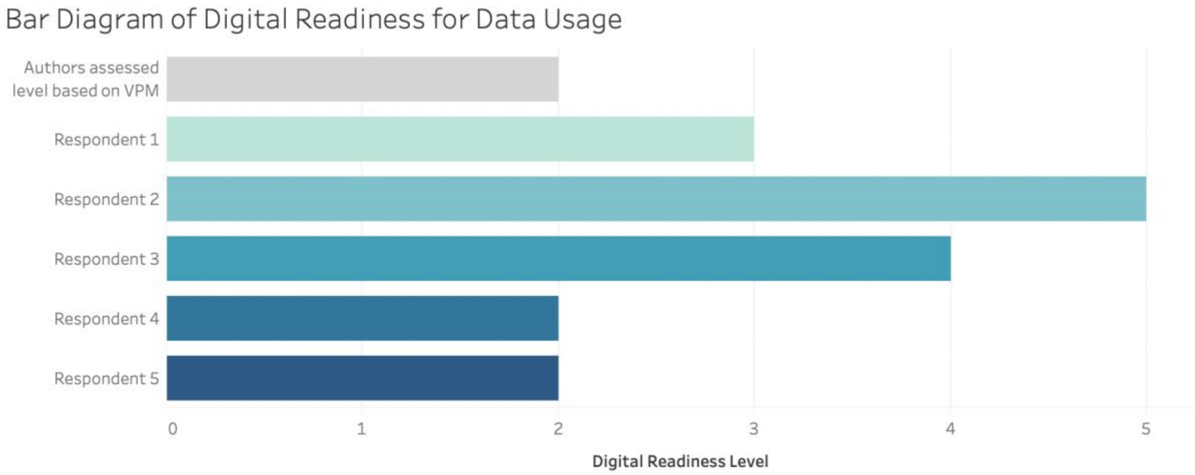

Diagram 10. Bar diagram showing the assessment of digital readiness for the field data usage.

The fact that the respondents might have had the entire operations in mind in contrast to the specific process of production loading, which was the perspective for the VPM assessment. This could be a reason why the respondents' answer levels differ from the result in the VPM.

Another reason can be due to the potential different interpretation of *optimization* between the authors and the respondents. Optimization can be interpreted, according to Gartner IT Glossary, as *the process of using digital technology to improve existing operating processes*. Which is in line with the respondents comment on level 4. However, another interpretation, according to Merriam-Webster dictionary, is *the process of making something (such as a system) as fully perfect, functional or effective as possible*. Which is in line with the authors' idea of optimization.

From interviews and observations, there are no activities in planning to use data for optimization in the way the term is interpreted by the authors. In other words, a model used for simulation to optimise processes does not exist from the authors perspective. Rather, data is used for manual analysis to gain insights on how the planning should be performed.

Despite the possible misinterpretations on the different levels and terms, an important take-away is that to reach a higher digital readiness, using data to improve processes is not sufficient. When optimization is referred to in the way to make processes as effective as possible, some measures need to be taken beyond the current use of data. Additional data needs to be collected to more advanced IT-systems for optimization of processes to be possible.

Reflection on the field data usage

For the assessment of data usage, the criteria are used to evaluate how well the data is used and to what extent. To reflect directly on the criteria used for data collection, this was evaluated based on the extent of data collection rather than the quality of the data collected. The field data usage is thought to give a good understanding of the actual digital readiness within the concept of data usage. However, due to the possibility of the different interpretations of optimization, the validity of the field could be improved.

5.1.6 IT Systems

Assessing Digital Readiness based on insights from VPM

The field IT systems measure the extent of IT Systems usage and the extent of integration between processes and IT systems. From a company-wide perspective, the use of internal IT systems is extensive. Though, the focus is on the loading process and the integration of IT systems between the sub-processes concerning planning, performing and follow-up.

IT systems currently used are GIRON, WOLIS and Mobilaris. GIRON is a data management system with some features of an ERP-system, e.g., decision support such as dynamic loading and information sharing such as the interplay between operator, mine control and service personnel. WOLIS is used to collect and show data relevant mainly for the operators to support their performance. WOLIS is integrated with GIRON and data can be transferred between the two systems. Mobilaris helps to visualize the mine and the location of LHDs and workers.

Even though most information is collected with GIRON, most of the data is used with the personnel accessing and extracting the data before analysing and gaining insights of the data. An example is that information on disruptions in production loading is filled manually and needs to be interpreted and analysed by a mine planner who actively entered the right Excel sheet for information. This is not an example of an *integrated* system. Rather, GIRON is a united data management system with fragmented sheets available for all employees to access.

To answer the achieved level, it becomes clear that processes are supported by IT systems and that some of the processes and IT systems are integrated, such as WOLIS and GIRON. Since WOLIS and GIRON are integrated to one another for dynamic loading, the assessed digital readiness level for IT systems results in *level 3*, described as *"some areas of the business are supported by IT systems and integrated with one another"*. However, it should be clear that this is just *one* example and that there should be more work to strengthen the integration between IT systems before moving forward. To achieve level 4, complete IT support of processes and full integration is needed. Today, LKAB is far from achieving this due to processes including a large number of manual handling between systems that need to be integrated before proceeding further. Also, there are areas such as communication and collaboration between divisions that lack a functional IT system to simplify the teamwork. Here, instead an establishment of an IT system or features within an existing IT system is needed before going forward.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

Two of the respondents answered that the readiness was at level 2, described as *"Some areas of the business are supported by IT systems and integrated"*. The rest of the respondents answered level 1 *"main process supported by IT systems"*, level 3 *"some areas of the business are supported by IT systems and integrated with one another"* and level 4 *"complete IT support of processes, full integration"* respectively. Comments related to the field are shown in Table 12.

Table 12. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 2 – *Some areas of the business are supported by IT systems and integrated.*	"The most important processes are automated and integrated."
Level 4 – *Complete IT support of processes, full integration*	"IT is used for all processes but is not fully integrated in all parts of the business."

The discrepancy between the answers is again thought to be due to the word *integration*, varying to the extent of being non-existent, integrated, integrated with one another, or full integration. Even to the authors, the difference in the meanings is not simple to grasp.

Further, since the questions uses the word "business", the respondents are highly likely to have thought of the business processes as a whole. Meaning that, even though integration with IT systems between activities within production loading is problematic and known or even expressed earlier by the respondent, the field assessment is likely based on the comprehension of the IT systems at LKAB as a company. This is strengthened by the comment related to the person assessing IT systems at level 4, commenting that all processes are supported by IT but not fully integrated with all parts of the business. This comment is likely to mean that the processes *drilling, blasting, production loading* etc., or even *processing (the beneficiation of iron ore)* is supported by IT, rather than to mean that the different activities within production loading is supported by IT.

From the answers, it becomes clear that the respondents concur of LKAB having IT systems in use. However, the extent of the integration between systems differs.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to IT systems and the assessed digital readiness based on the VPM is shown in Diagram 11.

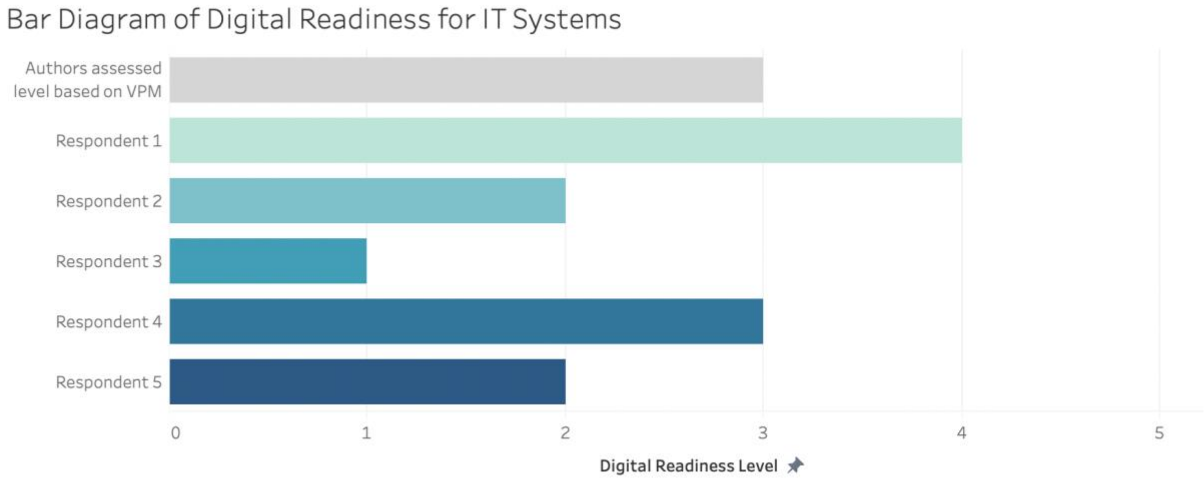

Diagram 11. Bar diagram showing the assessment of digital readiness for the field IT systems.

The assessed digital readiness varies a lot for the field. To compare the assessment using VPM with the respondents' answers, it is likely to be different due to the readiness level assessed using the result from VPM focuses exclusively on production loading. Whereas the respondents are thought to have focused on the business as a whole.

Reflection on the field IT systems

As the result from the respondents shows, the accuracy of the assessment for IT systems is not the best. The large discrepancy from the respondents can have different causes. Two identified causes are either that the business area referred to differs between respondents or that the word integration is difficult to interpret or understand.

Apart from that, the field of IT systems is relevant for assessing digital readiness due to its potential for improving communication, information and data sharing. However, the field investigates the extent of IT systems used and the integration between these, but the actual outcome from the usage of IT systems is not covered. For example, in production loading there are IT systems in all activities and as discussed, the different IT systems are integrated for some features. However, there is no criteria whether the features are relevant or having a positive impact.

5.2 Analysis of production processes through the perspective of Smart Operations

5.2.1 System-integrated information sharing

Assessing Digital Readiness based on insights from VPM

The field aims to assess which level the information sharing at LKAB achieves according to the different levels. The levels depend on how integrated the information is between systems both internally in the production loading and externally to vendors.

System-integrated information sharing in "Plan and inform where to load"

To start, the mine planners have one system to create long- and short-term plans. The information from these plans is then divided into weekly and daily plans on Excel sheets that are shared to the mine control and operators. There is a lack of integrated systems between these tasks, which entails tedious manual updating in each Excel sheet.

Furthermore, the scheduling of supporting tasks like maintenance and reparations does seldom take the production plan into account and vice versa. This sometimes leads to downtimes that could have been avoided. They could be avoided through two ways. First, by planning supporting tasks to be performed simultaneously instead of after each other. Second, they could be planned to not interrupt with the on-going production. Hence, information sharing on how each division plans their work would possibly give support for a unanimous schedule permeated by minimization of downtime in production. Also, if planners collaborate with other divisions during the planning phase to a greater extent, it may result in an optimization of LHD utilisation. The described examples of information sharing are summarized in Table 13.

Table 13. Summary of information sharing and level of integration for "plan and inform where to load".

Information sharing	System integration
Planning information between the mine planning, mine control and operators	Not integrated in one system. Spread on different platforms.
Planning information between the mine planning and the divisions for support functions	No integrated system or communication to make a coherent plan.

System-integrated information sharing in "Production Loading"

To support the operator performing the production loading, information is shared to support the decision to continue to load or not, referred to as dynamic loading previously. This information is enabled by the integrated equipment infrastructure between the ICTs on the LHDs, the production support system, WOLIS, and the IT-system, GIRON.

However, the total information the operator receives in the LHD is fragmented on different screens and devices. Also, the information in individual devices is sometimes experienced as fragmented such as for the operator's cell phone where both the daily shift plan and the operator's individual loading schedule are available but not integrated optimally. It becomes clear that the problem is not the information sharing by itself, but the integration of the different information channels to make it easier to access and use.

Whenever the operators encounter a problem, this information needs to be shared within the company. The flow of information between divisions is performed using the integrated system where error or support orders can be placed and followed in real-time. Although there is system-integrated information sharing as described, there are still tasks performed and errors reported through phone calls back and forth between mine control, service and operators.

The more automatic the LHD becomes, the more information needs to be shared directly between the machine's network and the overall IT systems due to the absence of a human operator that otherwise communicates what the LHD cannot. The main problem for this type of information sharing is the system integration with external suppliers. The LHDs are purchased from different vendors and their equipment and systems might not be interoperable with the systems of LKAB. In addition, the vendor might be sensitive towards sharing information from the LHD networks to LKAB, especially if they are one vendor among many. Therefore, there is ongoing R&D work with multiple affected vendors in the SUM-project that aims to find a solution on how to integrate equipment infrastructure between vendors and what information that can be shared. The described examples of information sharing are summarized in Table 14.

Table 14. Summary of information sharing and level of integration for "production loading".

Information sharing	System integration
Decision support for production loading (Dynamic Loading)	Integrated IT systems and physical equipment
Information to operator in LHD during loading	Not integrated, shattered on different physical devices and different interfaces
Error and support orders	Integrated system exists but is not always used
Information between LHDs and other machines during loading	Not integrated, hindered by interoperable systems and sensitivity of sharing information from different manufacturers

To sum up, there is information sharing internally in the production loading. Not *predominantly*, but *some* of this information is integrated between systems and some is not. The aim to solve the integration and information sharing from the vendors LHDs gives a proof on beginnings of initial external system-integrated information sharing in production loading. Hence, production loading at LKAB is at a *level 3* when it comes to system-integrated information sharing. To achieve the next level, it is needed to achieve improved information sharing and integration with external partners, as discussed for the LHDs. Internally, the information flow to the operator during production could be compiled to one platform. Also, system-integrated information sharing between divisions during planning and production needs to expand. Lastly, improvements to achieve a seamless handling of information during the planning phase is an additional factor for LKAB to level up.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model
2 out of 5 of the respondents answered that the readiness was at level 3, described as *"Some in-company and beginnings of external system-integrated information sharing"*. Two respondents answered level 5, *"Comprehensive in-company and partially external system-integrated information sharing"***.** The last

respondent answered level 2, meaning that *"in-company information sharing partially system-integrated"*. Comments related to the field are shown in Table 15.

Table 15. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 3 - *Some in-company and beginnings of external system-integrated information sharing*	"We have multiple external partners with which we successfully share information."

The only comment left for this field was from the one respondent in the table. It is hard to analyse the answer since it is unknown what kind of information the respondent had in mind and on what organizational level of LKAB the respondent refers to.

With that said, the criteria in the different levels refer to "in-company" and "external" as outside the company. Which makes it highly suspicious that the respondents have thought of information sharing at LKAB as an organization and not in the production loading process specifically. Therefore, it is hard to interpret the different levels assessed by the respondents in this field.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to system-integrated information sharing and the assessed digital readiness based on the VPM is shown in Diagram 12.

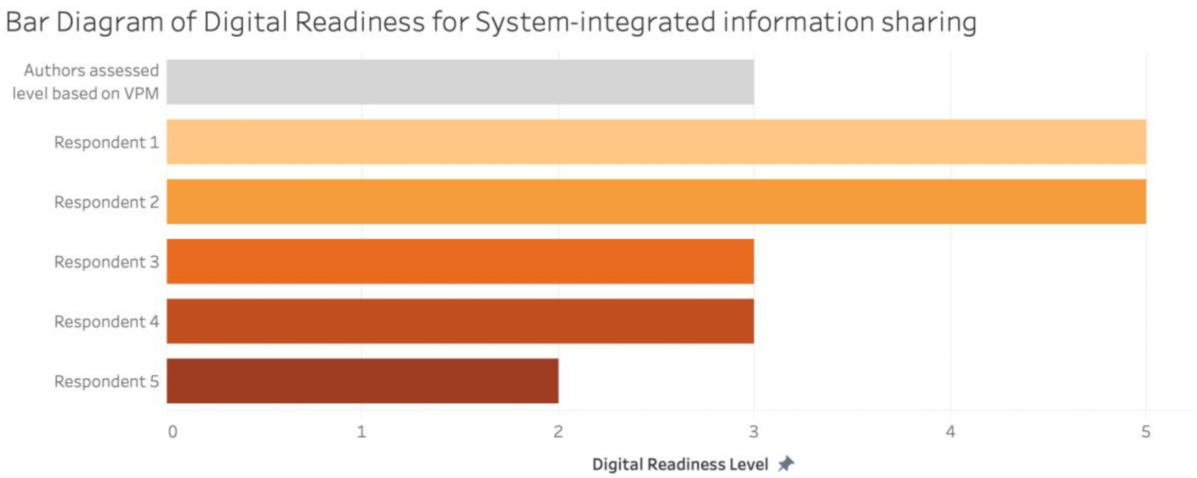

Diagram 12. Bar diagram showing the assessment of digital readiness for the field System-integrated information sharing.

The field is based on criteria that aim to capture the information sharing at a company level for the entire value chain. The authors evaluate the criteria in the production loading process which is a part of operations. Therefore, it is decided that due to the high risk of different perspectives between the respondents and the result from the VPM, a valid comparison cannot be done between the answers.

Reflection on the field system-integrated information sharing

The relevance for the field is assessed to be high. A well working and integrated information sharing between systems lays a foundation for the implementation of new technologies intended to improve the overall performance on the production loading process. Hence, much focus was placed on the assessment based on the VPM.

Although it was partially challenging to interpret the difference between some levels, the field captured the most relevant criteria into what extent information sharing exists and how the information is integrated between and within systems.

However, as discussed, the criterion for the different levels focuses on a company-wide information sharing. Due to the planned focus of the questionnaire was not communicated properly, the validity of this particular question for the assessment of production loading is thought to be limited when evaluating the result from the respondents. Nevertheless, the results from the VPM can be used for the case company to navigate towards possible improvements.

5.2.2 Autonomously guided workpieces

Assessing Digital Readiness based on insights from VPM

An autonomously guided workpiece can gather data on itself and its surroundings and communicate the data with IT systems to enable the workpiece to be guided through the processes autonomously. The field assesses whether such workpieces are used in the production loading.

To fully understand this field, it is important to clarify the difference between autonomous and automated systems. The difference between the two concepts is that automated machines and systems can perform well-defined tasks and produce deterministic results based on a fixed set of rules and algorithms. Autonomy refers to machines and systems with human-like cognitive, self-executing and adaptive abilities enabled by AI to perform tasks independently. (Xu, 2021)

Since the workpiece, iron ore, cannot be equipped with sensors and systems to collect data on its surroundings, the machines and mainly the LHD involved in the process are interpreted as the autonomously guided workpieces to collect information of its surroundings and in this way guide the iron ore through the process.

As of today, there are manual and semi-automatic LHDs but none of whom are autonomous. However, in the SUM project, there are experiments performed on the possible implementation of a transport management system (TMS) that would enable LHDs to determine routes and production sequences autonomously. Consequently, the production loading at LKAB holds a *level 4* in this field due to the experiments in SUM that are in the testing and pilot phase.

Level 5 implies that autonomously guided workpieces are *present* in the production process. To reach this level, the problems related to automation today, e.g., problems with reliability, flexibility and interoperability as discussed in section "*4.2.4.2 Interviewee's reflections on LHD"*, should be mastered before succeeding with autonomous LHDs.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

2 out of 5 of the respondents answered that the readiness was at level 4, described as *"Experiments in test and pilot phase"*. Two respondents answered level 5, *"Use in selected areas or even cross-enterprise"*. The last respondent answered that the question, or rather the word *workpieces*, was not understood. Comments related to the field are shown in Table 16.

Table 16. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Does not have sufficient knowledge to give answers.	"I do not understand what is meant by "workpieces""
Level 4 - *Experiments in test and pilot phase*	"We are trying different levels of automation in production and in planning process."

Level 5 - *Use in selected areas or even cross-enterprise*	"We use autonomous drilling rigs, loaders (LHD), trains and skippers"

The comment from the respondent that answered level 4 verifies that ongoing experiments are performed by mentioning that different levels of automation are tested in the production and planning process. On the note of *different levels of automation*, this seemed to have been misinterpreted by the respondent that answered level 5. Since the comment refers to rigs, LHDs, trains and skippers as being autonomous when they are in fact automatic. There is a risk that the other respondent that assessed level 5 reasoned in the same way.

Another reason could be that the criteria for the two levels can overlap in those *experiments* included in level 4 might be tested in *selected areas* included in level 5. For example, much of the initial use of autonomous solutions and experiments are performed in Konsuln, the test mine for the SUM-project, which can be considered as a *selected area*.

The field was not comprehensible according to one respondent. However, based on the rest of the comments and assessed levels. It seems like focus was directed from the word *workpieces* to autonomous solutions in general.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to autonomously guided workpieces and the assessed digital readiness based on the VPM is shown in Diagram 13.

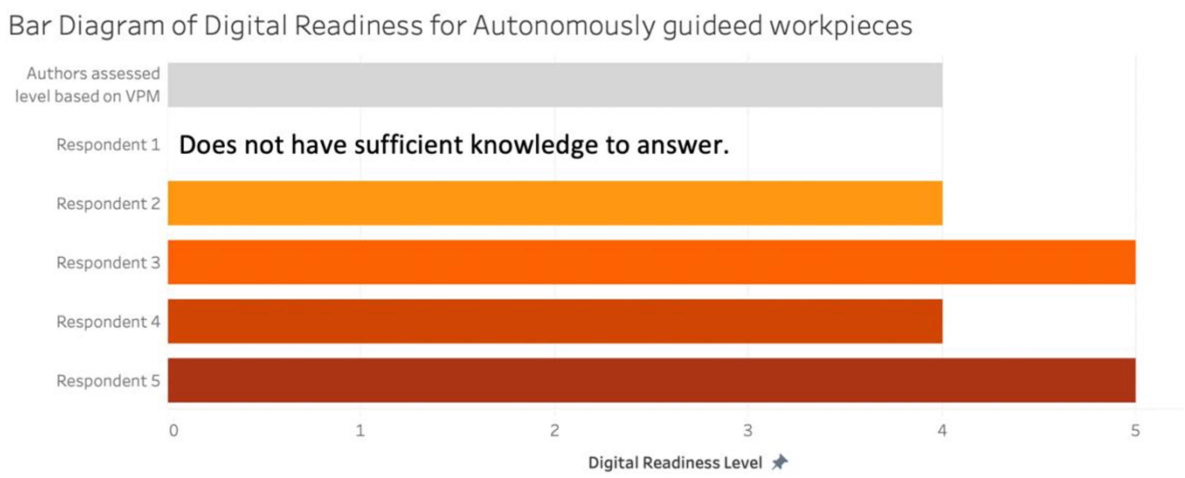

Diagram 13. Bar diagram showing the assessment of digital readiness for the field Autonomously guided workpieces.

Both the respondents and the authors directed focus away from the word *workpieces*. The authors thought of autonomously guided LHDs, and the respondents seemed to consider autonomous solutions in general. Consequently, the results are still deemed to be comparable.

Since one of the respondents did not answer, half of the respondents answered level 4 much like the result from the VPM. The comment on level 4 is well aligned with the reasoning of the authors. It is not possible to compare the result from the VPM with the comment on level 5 since there is a difference on what is considered as "autonomous".

Despite possible different interpretation of the criteria of the levels and the definition of autonomous, there is consensus between the result from VPM and the respondents in that the level is high, level 4 or above. What can be considered as an interesting take-away is that the complex technological applications such as autonomous workpieces (or machines in this application) are in a testing phase. At the same time, other fields such as equipment infrastructure and system-integrated information sharing, that could be considered as prerequisites to the implementation of autonomous solutions, are assessed to lower levels.

Reflection on the field autonomously guided workpieces

Autonomous solutions are relevant to the digital transformation and are therefore relevant to assess. The field treats "autonomously guided workpieces" which is originally thought to assess to what degree a physical object travels through the production autonomously in a traditional manufacturing industry with discrete products. To apply the field to mining, the "workpieces" was substituted with LHD's since the LHD's haul the ore through the production process.

The levels 0 to level 3 all have the same criteria "autonomously guided workpieces not in use". Which raises the question if the levels could be complemented for a more nuanced field. For example, other levels could have various levels of automation as criteria. Such as "*automatically* guided workpieces" where the workpieces are not guided fully autonomous but require a minimal degree of human involvement and predetermined travel routes.

The possible overlapping of level 4 and level 5 as well as the possible misinterpretation of the term "autonomous" among the respondents lowers the validity of the answers.

5.2.3 Self-reacting processes

A self-reacting process occurs when data is collected from smart products to identify what process that needs to be done next and initiates the process autonomously. The field assesses whether such processes are present in the production loading.

There are no signs of such examples in the production loading. The real-time feedback related to the status of the product in the production loading process in use today is the iron percentage content and tracking of the products location. The information of the iron content serves as decision support for closing the ring, but it does neither automatically terminate the process, nor initiate a new one. The information of the location tracking is used mainly for monitoring the process rather than to support self-reacting processes.

For the LHD to be guided autonomously through the entire production from loading to dumping, the processes need to be self-reactive as well. Therefore, the on-going experiments in SUM that experiments with autonomously guided LHDs also cover the field of self-reacting processes. Hence the level is *level 4*.

For the field to reach level 5**,** self-reacting processes need to exist in *some* areas. There might be many areas in the production loading where this is possible. One area is related to the example of an autonomous decision on abandoning a ring when the iron percentage in the bucket is not economically defensible. This requires advanced machine learning technology from example image analysis to replace the human eye in identifying rock characteristics. Before moving to this step, it makes sense to improve the existing solution. By for example calibrating the accuracy from calculating the volume of the content in the bucket. The increased accuracy of product information in the LHD bucket could trigger possibilities of additional self-reactive processes. One example is to integrate the rock-breaker with the LHD. Then it could receive data on rock characteristics such as fragmentation before an incoming batch and thereby prepare and perform an operation without human video surveillance.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model
4 out of 5 of the respondents answered that the readiness was at level 5, described as *"Use in selected areas or even cross-enterprise"*. One respondent answered he or she did not have sufficient knowledge to provide an answer. Comments related to the field are shown in Table 17.

Table 17. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 5 - *Use in selected areas or even cross-enterprise*	"Most control systems have a control model built in that provides "self-regulation" between actual and setpoint values." "I do not understand what is meant by "Self-reacting processes"".

The comments from the two respondents clarify that the description "self-reacting processes" is ambiguous and hard to understand. One respondent expressed lack of comprehension to the description but still answered level 5. The other comment shows that the respondent interpreted the description in terms of "self-regulation" which is indeed a natural interpretation. Consequently, there is a risk that the respondent has thought of self-reactive processes as processes that are performed without human assistance through control systems with self-regulation. Much as the semi-automatic LHD's operating automatically and with self-regulation when hauling and dumping ore.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM
The result from the question related to self-reacting processes and the assessed digital readiness based on the VPM is shown in Diagram 14.

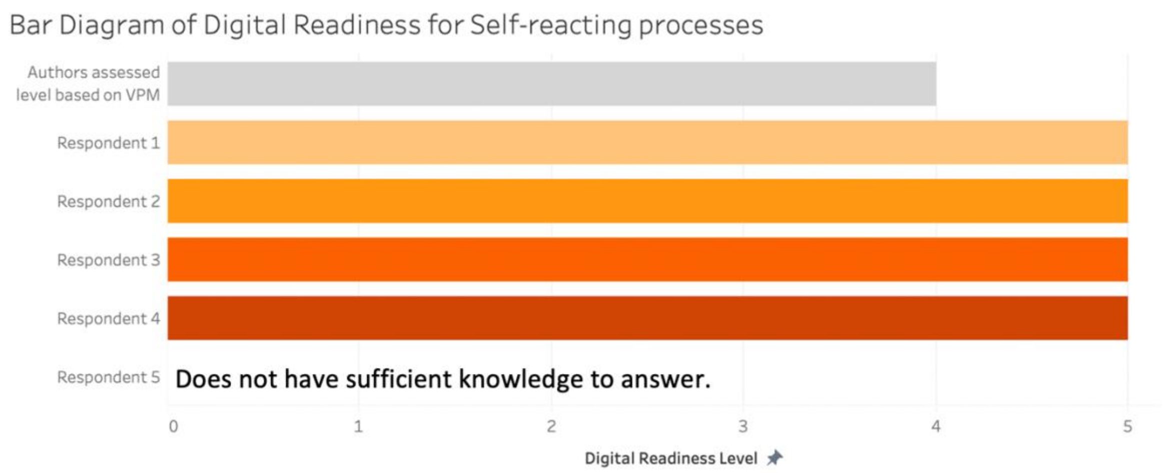

Diagram 14. Bar diagram showing the assessment of digital readiness for the field self-reacting processes.

A comparison between the result from the VPM and the respondents assessed levels is not feasible due to the different interpretations of the description "self-reacting processes". There is a high risk that the other respondents assessing level 5 has reasoned the same way as the one respondent that left a comment referring to "self-regulation". In contrast to the interpretation that has been used to assess a level from the VPM. Namely that self-reacting processes are triggered autonomously, meaning that assets *take their own decisions* based on gathered data to initiate and/or terminate an operation.

Reflection on the field self-reacting processes

As described in the analysis from the VPM, autonomously guided workpieces are a prerequisite for processes to be self-reactive. Both dimensions have a high relevance to eventually achieve a high digital readiness level. However, they can be seen as extraordinary in relevance to the importance of well working fundamental fields such as system-integrated information sharing and equipment infrastructure.

For reflections on the criteria, the same reasoning is done as for "autonomously guided workpieces". The field has the potential to be more nuanced. Again, level 0 to level 3 has the criteria "self-reacting processes not in use". Therefore, a request could be to include a wider range of the spectra of technological development in the processes. For example, some level beneath level 4 could be "self-regulated" or "automated processes" in use. This to emphasize existing steps towards autonomous self-reacting processes.

For the validity in the answers from the respondents, it is deemed to be low due to the lack of definition the respondents received before assessing a level on "self-reacting processes". As opposed to the authors that got a chance to study what is meant by the field. This logic of course applies to all the fields but should be extra highlighted for both "autonomously guided workpieces" and "self-reacting processes".

5.2.4 IT security

Assessing Digital Readiness based on insights from VPM

IT security relates to the extent of solutions implemented to securing data and processes from breaches. Ranging from no IT security solutions implemented to comprehensive IT solutions being implemented in all relevant areas. However, this has not been the subject for the VPM and therefore the information to assess a digital readiness for this field is thought to be insufficient to the authors. This field will therefore be left without any assessment.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

2 out of 5 of the respondents answered that the readiness was at level 4, described as *"Comprehensive IT security solutions have been implemented, existing gaps are being closed"*. One respondent answered level 3, *"IT security solutions have been partially implemented"* and another level 5, *"IT security solutions have been implemented for all relevant areas"*. The last respondent answered he or she did not have sufficient knowledge to provide an answer. No comments were left related to the field.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

Due to the limited answers and comments related to the field, both from VPM and from the IMPULS questionnaire, this field will not be compared.

Reflection on the field IT systems

Due to the limited application of the field, both from VPM and from the IMPULS questionnaire, this field will not be reflected upon.

5.2.5 Cloud Usage

Cloud usage, or cloud computing, as described in the theory section 3.3.1, is a computing model providing resources such as data storage, applications and services through an on-demand network normally accessed from a provider (Mell & Grance, 2011). The field assesses to which extent cloud solutions are used in production loading today. The fields range from no solutions, planned solutions, initial implementations and multiple solutions implemented.

In production loading, cloud computing services are on the rise of interest. Some solutions have recently been implemented and others are in the testing phase. As the data management system GIRON is upgrading to a new version that will support cloud-based services and modules, the aim is for LKAB to have multiple cloud solutions implemented.

Initial implementations exist in the mine planning. Production data is collected in GIRON and Power BI is used to create reports and visualizations for the mine planners from that data. The output by Power BI is used for presentations of the production data as well as it serves as a basis for further analysis by the planners. Since there is an initial implementation in use in production loading, the level is *level 4*.

It is not until more solutions are implemented that level 5 is reached. LKAB aims to reach this level by extending the number of solutions. One of them being to perform analysis in the cloud with the help of cloud-based services. In this way, useful output could be extracted without human intervention in the analysis. For LKAB to succeed with this, it is vital that as soon as possible, a transition is performed from the old to the new version of GIRON that supports cloud computing.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model
2 out of 5 of the respondents answered that the readiness was at level 4, described as *"Initial solutions implemented"*. Two respondents instead answered level 5, "*Multiple solutions implemented"***.** Comments related to the field are shown in Table 18.

Table 18. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 4 - *Initial solutions implemented*	"We use cloud solutions to a limited extent today, but within 2 years we will have extensive cloud solutions"

The comment from the respondent that answered level 4 is in line with the criteria of the level. The explanation of the limited usage of current cloud solutions matches with "initial solutions implemented". Furthermore, the emphasis on future extensive cloud solutions implies that level 5 "*multiple solutions implemented*" is in sight.

Besides from the one respondent expressing to not have sufficient knowledge to answer, two respondents answered level 4 and two respondents answered level 5. Since the criteria in the levels are simply grades of to what extent cloud solutions are implemented, they can be considered ambiguous. Nevertheless, there are possible reasons why the answers differ. First, "cloud solutions" is a technology that might not be general knowledge. However, due to the overall technological knowledge that the selected respondents possess, this is not considered to be a likely reason.

A more likely reason for the different answers is again the organizational perspective of the respondent. While some respondents might refer to cloud solutions implemented in the production loading, others might refer to all operations or even LKAB on an organizational level.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to cloud usage and the assessed digital readiness based on the VPM is shown in Diagram 15.

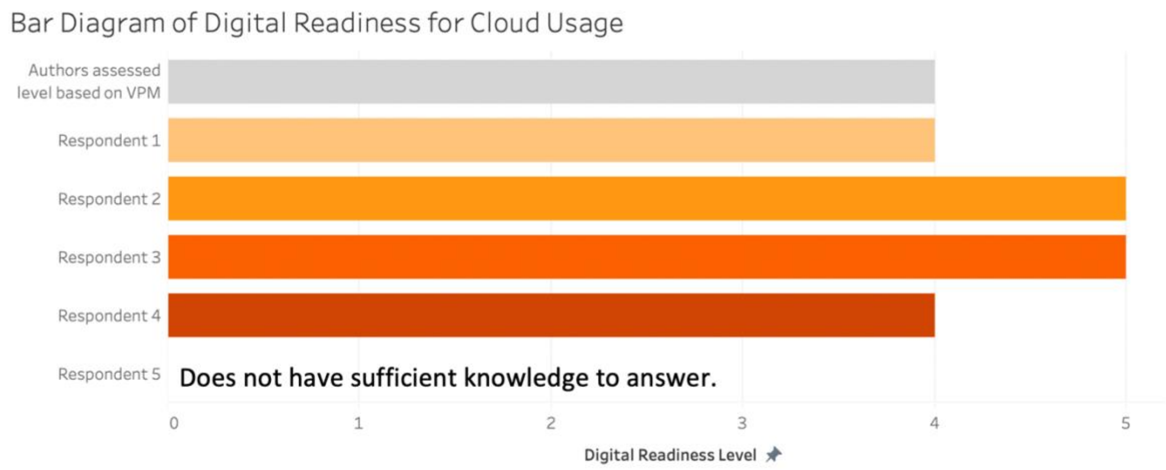

Diagram 15. Bar diagram showing the assessment of digital readiness for the field cloud usage.

The comment from the respondent that answered level 4 implies the same findings as from the analysis of the result from the VPM. Namely that initial implementations are existent and the aim towards a more extensive usage of cloud solutions is ongoing.

The respondents that answered level 5 did not leave a comment to explain why they did so. Hence, it is not possible to investigate the difference with the result from the analysis of the VPM. The same possible reasons for why there is a difference among the answers of the respondents apply to the comparison between their answers to the result from the VPM.

Despite possible misinterpretations, an agreement exists that the readiness is high in this field. This is remarkable since some fundamental levels that can be interpreted as prerequisites to "cloud usage" such as "data collection", "data usage" and "IT-systems" all score lower levels.

Reflection on the correctness of the field cloud usage

"Cloud usage" implies usage of cloud computing which is identified as one of the enabling technologies for a digital transformation. It is considered relevant to exploit the current cloud solutions and plans for coming implementations in assessing the digital readiness. However, it is questionable that it scores higher than some other fields that, according to the authors, need to work properly before cloud solutions can be utilised to its full extent.

The criteria in the levels are sufficient in capturing the digital readiness when it comes to the existence of cloud solutions in the production loading.

The validity of the answers from the respondents can be questioned due to the possible different organizational perspectives that were in mind when assessing a level. However, since the field is not particularly extensive but rather narrow in evaluating if cloud solutions exist or not. Focus should be put on the comments that are in line with the result from the VPM. The match is not surprising since the person in question works in the production loading. Furthermore, much of the information gathered in the VPM regarding the relatively small subject of cloud computing comes from this specific respondent. Regardless, the risk of bias is not considered relevant since the field is binary in that either cloud-solutions are implemented to the extent that the level suggests, or they are not.

5.3 Analysis of production processes through the perspective of Smart Products

5.3.1 ICT add-on functionalities

Assessing Digital Readiness based on insights from VPM

A smart product collects data on itself and its surroundings by ICT technologies to be used for analysis and improve production processes. According to Lichtblau et al. (2015), smart products are the physical objects that are produced in the production process. In the case of LKAB, this product is iron ore. Hence, the product is not suitable to equip with ICT technologies. However, data on the product is still collected from the LHD, holding the iron ore through the loading process, with ICT equipment. Today, the LHDs are equipped with RFID tags for localization and sensors for object information as described more in the next section.

It becomes evident that the product features *some* add-on functionalities, localization and object information. Consequently, LKAB is at *level 2* for this field. For achieving the next level of readiness, *multiple* and *interrelated* add-on functionality is requested. To achieve this level, add-on functionalities should be added such as to improve accuracy in dynamic loading by also measuring the volume of the content in the bucket and functionalities on rock breaker to identify disruption in flow due to rocks being stuck at the grid to the ore passes. Additionally, insights of the problems related to uneven flow of rock or hang-ups is thought to possibly be improved with the use of add-ons.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

Two of the respondents answered that the readiness was at level 3, described as *"Products feature multiple, interrelated add-on functionalities"*. One respondent answered level 2, meaning that *initial* features were used. Another respondent answered level 5, *"Products feature extensive add-on functionalities"*. The last respondent answered that he or she did not have sufficient knowledge to answer. Comments related to the field are shown in Table 19.

Table 19. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 2 – *Products feature initial add-on functionalities*	"Here we are dependent on the suppliers and what they equip their machines with. There are also so many standards in this area that it is difficult to scale. We also have a large part of our business underground, which does not make it easier."
Level 3 – *Products feature multiple, interrelated add-on functionalities*	"In each location there is an RFID tag that tells the loader which location and ring is loaded and to which shaft, we also have RFID tags on our trucks in the truck loop as a safety aspect for the truck to be in position before you start dropping."

Level 5 – *Products feature extensive add-on functionalities*	"If you mean machines and equipment used in the manufacture of the products, this is used to a large extent."

The respondent answering level 2 argued clearly on the difficulties of implementing add-on functionalities on their machines, such as dependency on suppliers and the difficulties of being underground. Since LKAB does not have a product to directly equip with ICT add-on functionalities, much of the devices are placed on machines related to operations, such as the LHD. However, add-on functionalities can also be placed in a nearby environment to track the performance of the process.

The respondent answering level 3, meaning that *multiple, interrelated* add-on functionalities are used, provides examples for his or her thoughts. The examples are to use RFID tags to collect data on location and use it for improved security and tracking where loaded from and where dumping happens. It can be thought that calling this *multiple, interrelated* add-on functionality is a bit too optimistic. However, it is possible that the respondent had other examples in mind which were not commented on.

The last comment relates to the respondent answering level 5, stating that add-on functionalities on machines and equipment used in manufacturing is used to a large extent. Unfortunately, the respondent did not provide any examples. However, respondent 2 is working with automation on a daily basis throughout the mine. On one hand, the respondent should have more insights than any other of the respondents. However, there is also the possibility of being biased. Additionally, it is likely to think the respondent thinking of the entire operations instead of only within production loading, which is more likely to result in the assessment of *extensive* add-on functionalities in use.

Summarizing, the respondents are concurring on the existence of add-on functionalities at LKAB but to what extent is varying.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to ICT add-on functionalities and the assessed digital readiness based on the VPM is shown in Diagram 16.

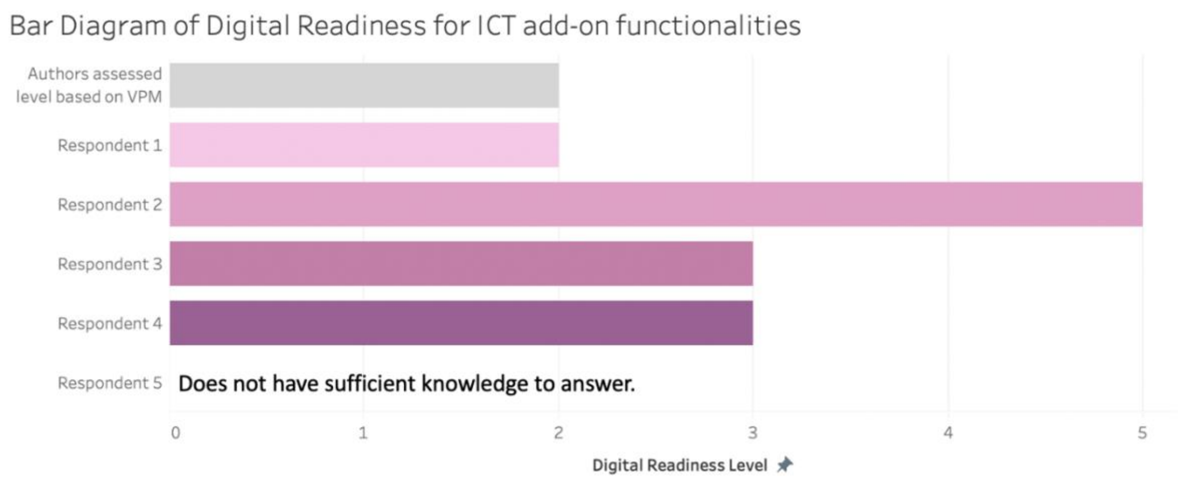

Diagram 16. Bar diagram showing the assessment of digital readiness for the field ICT add-on functionalities.

From the comments by the respondents, it seems as they interpreted the question similar as the assessment used from the VPM, meaning that the machines and equipment were analysed on their usage of add-on functionalities. This is due to iron ore being difficult to equip itself.

From the comments, it becomes clear that at least some respondents are familiar with the difficulties of add-on functionalities. Also, a respondent gave examples similar to the ones the authors have identified. However, one respondent's answer stands out being at level 5. To compare to the authors assessment, and the insights from the VPM, it is hard to motivate such a high level when looking at production loading. However, if the perspective is operations as a whole, it is much easier to reason.

Reflection on the field ICT add-on functionalities
The field is relevant for the digital readiness since it is one of the basics for data collection, providing the company with information to transform it into actionable insights. The criterion of the field is relevant and measures the extent of add-ons installed. The actual usage of the data is evaluated in upcoming the field. However, the quality of the data is not assessed.

Additionally, for a product such as iron ore, it becomes problematic with the formulation of add-ons on the *product*. However, as discussed, most of the respondents including the authors instead evaluated the usage of add-on functionalities on machines and equipment related and involved in the process.

5.3.2 Use of data

Assessing Digital Readiness based on insights from VPM
This field aims to evaluate if the collected data through ICT add-on functionalities is used or analysed. The sensor equipment placed on the LHD sends data that yields information on the product, e.g., iron content in the ore and bucket weight. This product characteristic serves as decision support on whether to proceed production or abandon the production segment. Furthermore, the RFID tags placed on the LHD sends signals to readers placed in each tunnel and each ore pass. By this, the RFID technology enables detection of surroundings and its location. The data collected and its usage is summarized in Table 20.

Table 20. Showing examples of data collected using ICT add-on functionalities and its usage.

Data collected	Use of data
Weight in bucket	- Analysed to gain information on iron content used for decision support on whether to proceed production or abandon the ring. - Follow-up on extraction goals, and to analyse the outcome.
Location information	- Follow-up on productivity and extracted tonnage for particular segments - Improved security

Summarizing, the data collected using add-ons are used and analysed, both automatically and manually. This results in the assessment of the highest achievable level for this field, *level 3*, described as *"data used/analysed"*. However, there is still potential to collect even more data using ICT add-on functionalities and improve the usage of the data, e.g., to improve decision support, having more accurate location tracking or improving the analysis of planning and follow-up.

Therefore, even though the highest level is achieved, the field has a lot of potential for improvements.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model
Three of the respondents assessed the use of data collected with ICT add-on functionalities to be on level 3, described as *"Data analyzed/used"*. One respondent instead answered level 2, *"Data collected but not analyzed/used"*. Lastly, one respondent answered that he or she did not have sufficient knowledge to answer. No comments were left related to this field.

Most respondents have the perception of data being analysed and/or used. However, one respondent answered that it was not analysed nor used. Since no comment is left regarding the field, it is hard to make connections to why a certain answer was picked.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM
The result from the question related to use of data and the assessed digital readiness based on the VPM is shown in Diagram 17.

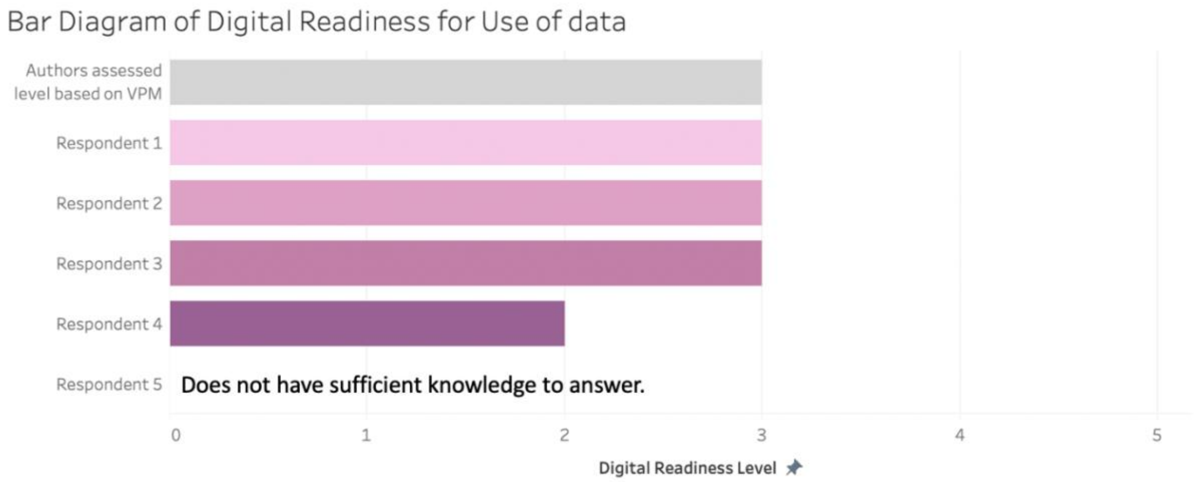

Diagram 17. Bar diagram showing the assessment of digital readiness for the field use of data.

Most of the respondents and the authors, both assessed the digital readiness to be at the highest achievable level for this field, namely level 3, "*data analyzed/used*". From the authors perspective, based on the VPM, it is clear that data collected through ICT add-on functionalities are used.

Reflection on the correctness of the field use of data
The field is relevant for the assessment of digital readiness due to smart products, and its data is the basis for having a smart operation and a smart factory. Meaning, it is the smart products that collect the data later used throughout the smart operations and smart factory, i.e., communicate with self-reacting and autonomous guided workpieces or to collect data later to be shared with extensive IT systems.

However, the field is thought to be insufficient due to the highest achievable level being that data is analysed or used. The extent of use of data, and how these support processes, is requested. A categorization of if the data is used for manual analysis or increased transparency, or if it is used to guide autonomous workpieces or optimise processes, should be done.

To lastly reflect on the correctness of the field, it is thought that the respondent understood the question and no comments on any confusion were left. Therefore, it is thought the correctness of the field is high.

5.4 Analysis of production processes through the perspective of Employees

5.4.1 Employee skills

Assessing Digital Readiness based on insights from VPM

The digital transformation undertaken by LKAB has severe effects on employees due to new technical implementations at their workplace. According to Lichtblau et al. (2015), successful digital transformation is dependent on the degree of relevant skills among the employees. It became clear from the interviews that technological skills depend on age, working tasks, general interest in technology and attitude towards digitalization. Since LKAB is a big company with many employees, there is a remarkable difference in skills, and it is hard to evaluate an employee's skill level without further research. However, it is also understood from the interviews that a lot of experience and knowledge exists, but that it is segregated. Some interviewees referred to each other back and forth without a clear understanding of the other's work. To coordinate this segregated knowledge, the desire for a person or division, with overall knowledge from different areas, was expressed.

Further, it was possible to assess how LKAB is working towards improving the attitude towards digitalization and increasing the skill levels among the employees. To reduce the hostility towards digitalization, the IT department aims to work closer to operations to identify key problems to solve instead of looking for solutions to many problems. To increase the level of skills, education, training, and workshops are performed but from some employees' point of view, this needs to be done to a larger extent.

Employee skills will vary depending on age, interest and work tasks. Although, the perception is that employees often have adequate skills in the area where he or she works. However, due to the many on-going projects and frequent implementations of technologies, it becomes too big of a challenge for IT to get all employees involved in every project which results in that the employees have adequate skills in *some* relevant areas, leaving the readiness to be of *level 3*. To achieve level 4, relevant skills in *several* areas are needed. For this, two approaches are thought to be needed. Both to deepen the knowledge within areas for advanced understanding for improvements, and to broaden the collaboration between divisions to understand each other's difficulties and opportunities.

Analysis of the result from questionnaire to assess Digital Readiness using IMPULS model

Two of the respondents answered that the readiness was at level 3, described as *"employees have adequate skill levels in some relevant areas"*. One respondent answered level 2, meaning *"Employees have low skill levels in a few relevant areas"*. Another respondent answered level 4, meaning adequate skill levels were met in *several* relevant areas. Lastly, a respondent answered level 5 *"Employees possess all necessary skills in several relevant areas"*. Comments related to the field are shown in Table 21.

Table 21. Includes the comments related to the field from the questionnaire.

Assessed level and its description	Comment to the answer
Level 2 – *Employees have low skill levels in a few relevant areas*	"I would say that we have a fairly low level of competence because many of our systems are

	outdated and we have not succeeded in developing them where we want."
Level 3 – *Employees have adequate skill levels in some relevant areas*	"Level of competence is probably varying a lot"
Level 4 – *Employees have adequate skill levels in several relevant areas*	"Difficult question, but LKAB has for a long time required 3 years of high school education when recruiting. Where the increasing use of IT in production and also enable change of future tasks is an important parameter"

The responses are scattered for this field and no clear consensus on the skill levels for employees in the different areas exists. The comment on level 2 reflects the level of competence in the insufficient development of systems.

The comment on level 4 takes an angle on skill acquisition and emphasizes parameters that are looked after in the recruiting process such as educational level, IT competence and the ability to contribute to change. Furthermore, the respondent expressed that the field was hard to answer which also can be seen from the comment on level 3 that emphasizes on the variety of competence in LKAB.

Again, the perspective on where in the organization to assess employee skill level results in some consequences leading to different answers. Not only does it result in different answers but also brings a difficulty in assessing a level due to the natural variation in skill level depending on which part of the organization the field refers to.

Comparison of Digital Readiness Level with IMPULS using the questionnaire compared to the result from VPM

The result from the question related to employee skills and the assessed digital readiness based on the VPM is shown in Diagram 18.

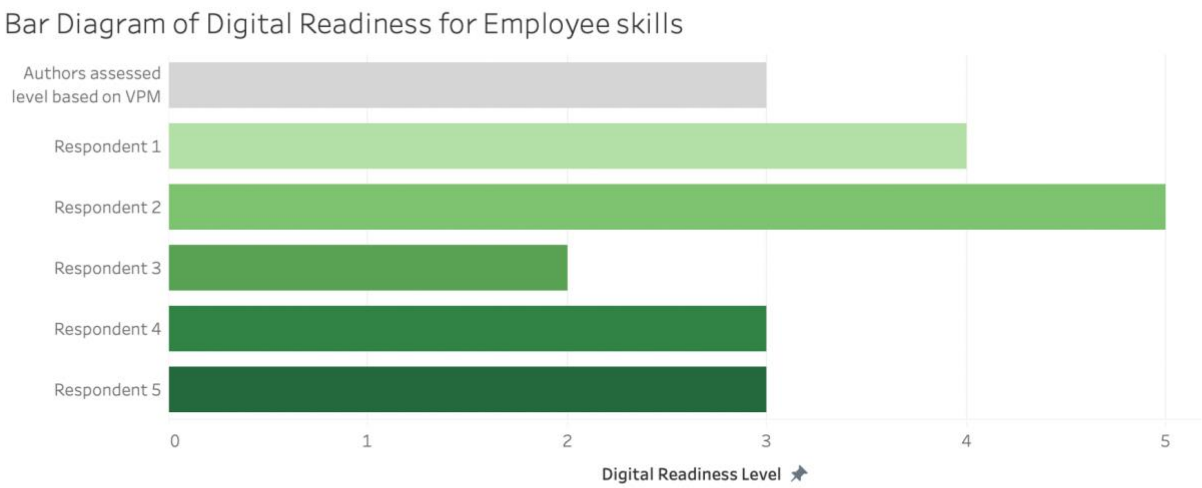

Diagram 18. Bar diagram showing the assessment of digital readiness for the field employee skills.

The comment on level 2 is somewhat aligned with the result from the VPM even if the result from the latter is level 3. The expressed disappointment on some systems that are outdated or failed to develop in its intended way can be compared to the findings from the interviews where the general impression was that there are many projects that are launched which in turn can be to the expense of ongoing ones.

In addition, the comments on level 3 and 4 matches with the results from analysis of the VPM in the difficulty of answering on a general skill-level for the employees without further evidence. Therefore, the respondent of the comment on level 4 shifted focus to skill acquisition and development just like the authors. However, the respondent emphasised on important parameters looked for in a possible employee whereas in the analysis of the VPM, focus was put on continuous education with already existing employees.

Reflection on the field employee skills

As mentioned previously in the thesis, the employees are enablers of a company's digital transformation. Consequently, it is indeed important to analyse and highlight what level of skill the employees possess. However, there are some critiques.

For the design of the dimension, it is thought that "skill level" is not sufficient to assess a level in digital readiness entirely. The attitude towards the digital transformation is at least as important. Therefore, the dimensions "Employees" are requested to have another field that captures how employees embrace the changes that come with a digital transformation.

Furthermore, the sentences can be interpreted in different ways. Take level 3 for example *"employees have adequate skill levels in some relevant areas"*. This can be interpreted as that some areas have employees with adequate skill levels. It can also be interpreted as employees have skill levels in different areas. The latter was the chosen interpretation for the result in the VPM.

Due to the shortages in the design of the dimension combined with the lack of communication that the questionnaire was intended for production loading only, the answers from the respondents cannot be interpreted to one ambiguous answer or level. Which is seldom the case for the fields used in this readiness model. It does however highlight the employee's general perspective on skill level in the organization.

5.5 Summary of the Analysis

This section covers a summary of the analysis. First, an overview of the overall digital readiness and key takeaways related to IMPULS are presented. Thereafter, the three key objectives identified for LKAB to focus on in going through a digital transformation are presented.

5.5.1 Summary of Digital Readiness

The readiness level for a *dimension* is determined by the lowest achieved level for a field within that particular dimension. The result for each dimension's readiness according to the analysis based on VPM is elaborated upon in the following paragraphs.

Smart Factory
The dimension Smart Factory scores at *level 2*. This has three main causes. First, the integration of equipment is largely integrated to IT systems and can even be controlled through IT. However, the equipment is not integrated to each other, meaning machine to machine. This is seen as a prerequisite for reaching level 3 and facilitating interoperability for a smart factory.

Second, some machines can be upgraded without the need of being exchanged. However, there are still machines not upgradable due to lack of integration. This needs to be fixed for the entire fleet of equipment to be dynamic and flexible to improvements.

Third and last, data is shown to be used mainly for transparency rather than optimization of processes.

Smart Operations
The dimension Smart Operations scores at *level 3*. The dimension had the potential of scoring level 4 due to having experiments and pilot tests for both autonomously guided workpieces, self-reacting processes and cloud solutions. However, system-integrated information sharing is not utilised to the potential of a higher level than level 3. To reach a higher level, it is important to integrate information channels and share more information. This to facilitate communication between divisions and to reduce double work connected to a non-integrated information system.

Smart Products
The dimension Smart Products scores at *level 2*. Data is collected using add-on functionalities, such as localisation, bucket weight and more. However, there is still a lot of data needed to be collected and used for utilising the full potential of digitalisation. Examples related to LKAB are volume in the bucket to improve decision support or to start identifying rocks that are too big to go through the grid in the ore passes to create the essentials for making that process autonomous rather than automatic. Shortly, more valuable data is needed to be collected.

Employees
The dimension Employees score at *level 3*, meaning that adequate skills exist in some relevant areas. It could be argued that adequate skills existed in several relevant areas. However, due to the high pressure of IT division and the lack of understanding of how to grasp the full potential of digitalisation, it is assessed at level 3. There are simply a lot of complex projects at LKAB currently, and the expertise needed for the realisation of these projects is needed to be established and expanded within the company either with education or by hiring experts.

The overall digital readiness for the analysis is assessed by using the weighted system described in *section 3.4.3.3 Assessment of Digital Readiness*. The calculations, and the result, for assessing LKAB's digital readiness is shown in Table 22.

Table 22. Showing the calculations made for assessing LKAB's digital readiness according to the author's assessment.

	Calculations for assessing the Digital Readiness	**Assessed Digital Readiness for LKAB**
Authors' assessed level based on VPM	$2 * 0.23 + 3 * 0.16 + 2 * 0.31 + 3 * 0.30 = 2.46$	2 – Learner

The result of digital readiness according to the analysis performed based on VPM is to be compared with the overall digital readiness assessed by the respondents, shown in Table 23. The same table was found in the Empiric section.

Table 23. Showing the calculations made for assessing LKAB's digital readiness according to each of the respondent's answers in the questionnaire.

	Calculations for assessing the Digital Readiness	**Assessed Digital Readiness for LKAB**
Respondent 1	$2 * 0.23 + 4 * 0.16 + 2 * 0.31 + 4 * 0.30 = 2.92$	2 – Learner
Respondent 2	$2 * 0.23 + 4 * 0.16 + 3 * 0.31 + 5 * 0.30 = 3.53$	3 – Leader
Respondent 3	$1 * 0.23 + 3 * 0.16 + 3 * 0.31 + 2 * 0.30 = 2.24$	2 – Learner
Respondent 4	$2 * 0.23 + 3 * 0.16 + 2 * 0.31 + 3 * 0.30 = 2.46$	2 – Learner
Respondent 5	$2 * 0.33 + 2 * 0.24 + 0 * 0.00 + 3 * 0.43 = 2.43$ *	2 – Learner

*The calculation for respondent 5 was modified to be weighted with the same relative importance if smart products dimension were to be excluded. This due to no digital readiness level for smart products were able to be extracted for that respondent.

As can be seen, four out of five of the respondents' answers lead to the assessment of LKAB as a Learner. This is the same result as the analysis from assessing the Digital Readiness based on the insights from interviews and observations, i.e., based on the VPM.

However, it can be seen that there exist greater differences in assessed level when comparing each dimension and field separately rather than the overall digital readiness. Previously in the analysis chapter, section 5.1-5.4, each field was discussed in detail and analysed to elaborate on the cause of the discrepancy of each field. From this analysis, it was found that the differences in digital readiness between fields, in general, are due to three main reasons. That is:

- The questions were thought to focus on the production loading process exclusively. However, some respondents are likely to have answered the questions with the perspective of the entire operations and organization of LKAB, rather than with the perspective of production load. This is likely to have caused a discrepancy in the answers.
- Difficult words and concepts were not clarified to the respondents, which is why it is likely that some questions were interpreted differently among the respondents. This is likely to have caused a discrepancy in the answers.
- The respondents had different backgrounds within LKAB. Some respondents were originally from the production area themselves, while others had academic backgrounds

focused on a specific area. It is possible that this could have an impact on the differences in the answers.

5.5.2 Summary of identified key objectives in going through a Digital Transformation

Understand the full potential of collected data and use it optimally

The perception of how well LKAB is performing for collecting and using data is some of the fields varying the most when looking at the result from IMPULS. Relevant fields are thought to be data collection, data usage, ICT add-on functionalities, use of data and digital modelling. From the authors, LKAB is assessed to be level 2-3 for each of the fields. It is clear from interviews, observations, and questionnaires that some personnel think of it as the most relevant data is already collected and in use while others focus on the potential of additional data that can be collected. From the authors perspective, it has become clear that there is still a lot of data that can be collected to utilise the information it can bring.

One of the major insights to the authors is that it was somewhat unclear how much time was spent on different activities in production loading. Even though interviewees had a perception of the time spent, it was often an estimation. An example is the way to identify reasons for LHD downtimes, which is done manually today and was shown to be insufficient due to comments on the cause often being left out or hard to interpret. In a digital transformation, the company should apply digital technologies to identify those activities that have the most potential in contributing to improved productivity. To fully understand what activities that have the most potential for contributing to enhanced productivity, it is essential to understand what takes time and how often it occurs, meaning collecting data on incidents and their disruptions. For the LHDs, as an example, data on downtimes due to change of shifts, breakdowns, meetings or even coffee breaks are of importance to understand how to get the most value out of the LHDs.

Another central insight for the authors is that the visualisation of data is insufficient. It is hard to analyse and understand what cannot be seen, and the data by itself provides no information. Within production loading, and mainly its activities related to planning and follow-up, most of the data is monitored and analysed manually by a human before providing any information. It is time consuming and inefficient. Also, there is the risk that the insights are not communicated since they are not illustrated. This call for technologies of a digital transformation such as cloud computing and AI. There are cloud-solutions implemented at LKAB that could summarize and visualize the data with minimal human interaction. This is thought to provide analysts with comprehensible and correct information, illustrated in diagrams and graphs. The more advanced systems can perform big data analytics themselves independent of a human analyst. To access these features, LKAB needs to transition as soon as possible to GIRON 2.0 that supports cloud-based functions.

Even though data is collected today, more data is still needed to be collected. To identify what data should be collected, it is vital to truly understand how the data can be utilised. The ultimate goal of data collected should be to use it for optimization to achieve the highest potential productivity. Today, data in use can be categorised as used for increased transparency and support insights in improvements rather than optimising the processes.

Enable full potential of equipment by integration

Integration of the equipment infrastructure is seen as an important basis for LKAB to establish. LHDs are integrated with IT-systems to some extent today. However, the next step would be to integrate the LHDs with each other and with other machines. The integration of equipment infrastructure scores at *level 2* when assessed in IMPULS. At the same time, autonomous guided workpieces and self-reacting processes score *level 4*. However, it is thought that the integration of equipment is a prerequisite for autonomous guided workpieces and self-reacting processes.

Automation is vital for LKAB to support them in achieving increased productivity and decreased carbon dioxide emissions. A production system with a high level of automation must have integrated assets that communicate with each other. There are currently ongoing tests handling the integration of equipment from different vendors. If it succeeds, there will be a significant impact on problems related to interoperability. Meaning, LKAB can have equipment infrastructure from different vendors communicating with each other. First, an integrated production system with equipment from different vendors is thought of as a critical pillar to enable autonomous and self-reacting processes to be implemented in production loading. Hence, the interoperability will enable the usage of equipment from different vendors facilitating a higher degree of automation in the production. Second, LKAB can benchmark and take advantage of the competitive nature of innovations regarding digital technologies offered by several actors on the market as opposed to single sourcing and risk a lock-in situation with one vendor.

Additionally, an integrated system is more flexible for upgrades when new technologies emerge. Today, when the systems and machines are somewhat fragmented, the risk is that some parts are improved separately, and sub-optimized since the comprehensive view of the whole production system is absent. With an integrated system, applications can be implemented into the system without severe re-structures in the equipment infrastructure. At last, an integration of machines with the IT-systems enables data to be collected from the machines for LKAB to utilise. Much like the principles of IoT, the integration of assets enables a comprehensive data collection from many connected physical objects through sensor technology integrated with the IT-system. Furthermore, the functions applicable through cloud-computing solutions like big data analysis through AI can facilitate production planning, follow-up and even predictive maintenance if used right.

Simplify and improve the flow of information

The usage of IT systems needs to be improved to facilitate information sharing and communication. This is seen as an essential ground for digital transformation. From the conducted interviews and observations, it became evident that the current usage of IT-systems leaves room to make several processes more efficient. Examples are the double work in mine planning and mine control to update the production plan on different software systems, the absence of coordinated planning in production causing disruptions and the fragmented information flow to the operators.

To start, the manual updating of the production plan for both the mine planning and the mine control is permeated by structuring and moving data between systems, in this case GIRON and Excel. To enable a smooth working process and a better supervision of the plan from all parts, the information should be integrated with one system where all involved parts could access and update information. Furthermore, the same principle of integrated information sharing could facilitate a coherent production plan involving all relevant units to the daily production. Consequently, some unnecessary disruptions due to simultaneous activities at the same location could possibly be avoided if the mine planning and maintenance division collaborated and created a plan in a common system.

Another insight from interviews and observations was that communication is often more time consuming than needed. Despite that the database GIRON has an application to order support functions, a remarkable amount of phone calls is still done to mine control that coordinates the production flow. This can be due to many possible reasons where one can be the multiple screens and systems the operators receive information from. This high volume of uncoordinated information is thought to cause tedious working procedures, which influences productivity. Therefore, the aim should be to improve the information exchange by putting in the effort to enable a communication system inspired by the internet of things. The connection of physical objects to the internet could facilitate communication in that all relevant information for a person could be shared with one connected device. In this case, the operator. Additionally, in general, IoT can make data accessible for all relevant persons to check, change or analyse, resulting in fewer phone calls and time-consuming information sharing.

6 CONCLUSIONS

This chapter presents the conclusions drawn from the thesis, aiming to answer the purpose of this master thesis, to describe and analyse production processes to identify key objectives for a company going through a digital transformation.

To *describe* production processes, a method for process mapping called value-based process modelling was used. The model aims to gain insights for potential improvements by identifying some components to each process, sub-process or activity. The model succeeded to yield an in-depth understanding of each process and, at the same time, facilitate a comprehensive illustration of the entire process flow. The component *information* in the model was deemed to have extra importance for digital transformation since it highlights to what extent data is collected and how it is used. This insight for each process, sub-process and activity is deemed to be of extra relevance when the purpose is to analyse production processes in the context of digital technologies.

When *analysing* production processes, a model called IMPULS was used to support the understanding of relevant aspects for digital transformation. The application of the model is to assess the digital readiness of a company, and it was adjusted to satisfy the purpose of this study. It served as a framework for analysing the digital readiness of the case company with respect to their production processes and for identifying key objectives to go through a digital transformation. The model was found useful for highlighting the relevant areas to investigate when identifying key objectives.

At last, key objectives were identified for a company going through a digital transformation. The main objectives were to *understand the full potential of collected data and use it optimally*; *enable full potential of equipment by integration*; and to *simplify and improve the flow of information*. These are identified for a company assessed as being a Learner using the IMPULS model. However, when studying previous findings from assessing the digital readiness using IMPULS, it can be found that 17.9 per cent of companies are considered Learners and 76.5 per cent are considered Newcomers. Only 5.6 per cent are considered Leaders, meaning that those companies have already passed the classification of a Learner. All in all, the results and the key objectives identified for going through the digital transformation is thought to be applicable for companies within manufacturing or similar today.

7 CONTRIBUTIONS AND REFLECTIONS

7.1 Contribution to the academia

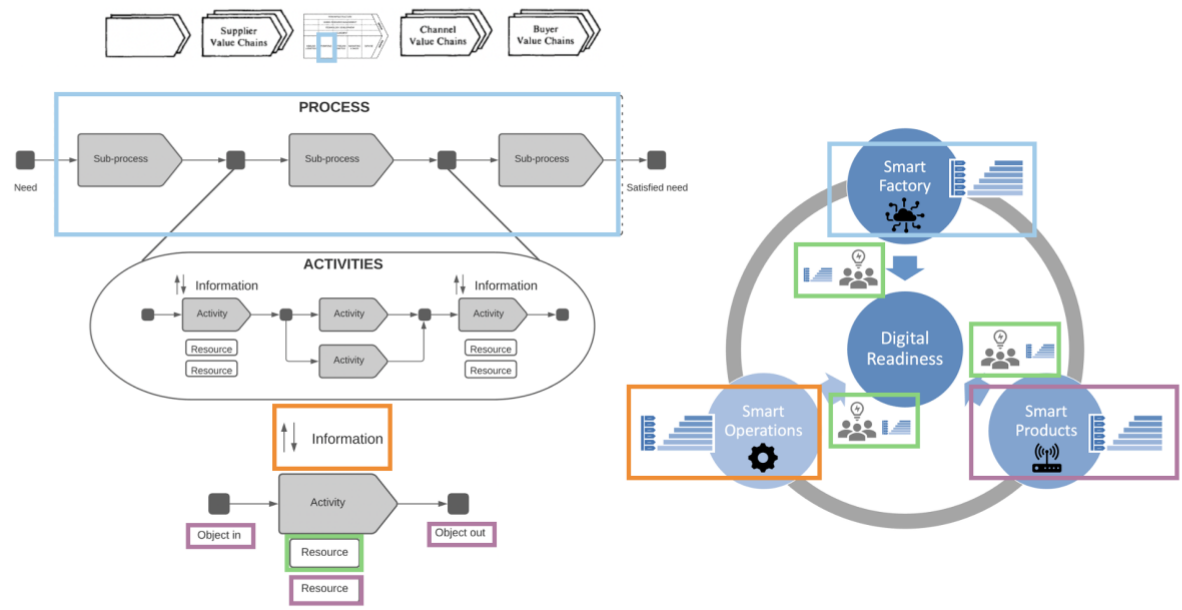

Figure 48. Illustration of AxAl-framework. Using value-based process modelling as a complement to IMPULS, proven to facilitate companies to understand how to proceed a digital transformation.

To answer the purpose of the master thesis, *to describe and analyse production processes to identify key objectives for a company going through a digital transformation*, the authors elaborated on value-based process modelling (VPM), digital transformation technologies and methods for assessing digital readiness (IMPULS). The literature study gave the authors the insights and inspiration for developing a new theoretical framework. A framework combining a model for mapping and understanding processes with a model for assessing digital readiness. The framework is named after the authors themselves and referred to as the *AxAl-framework*.

The *AxAl-framework* is successfully combining the two models, VPM and IMPULS, that complement each other. VPM complements IMPULS to facilitate understanding a specific activity or task belonging to a process that needs to be improved to achieve a higher level of digital readiness. IMPULS complements VPM by guiding the practitioner on what to focus on when investigating the process in a context of progress in digital transformation.

The authors have tested the *AxAl-framework* on LKAB and are overall satisfied with the outcome. However, a few remarks for the application and potential improvements of IMPULS were noted:

- All the dimensions in IMPULS were not applicable to use for specific *processes*. This due to some dimensions had fields that were based on measuring companywide phenomenon. For example, the dimension *strategy and organization*. To make IMPULS more applicable to investigate selected processes, some adjustments in the criteria for assessing levels in the fields are needed.
- IMPULS had some limitations when applied to the mining industry. For example, the dimension *smart product* is originally meant to measure data collection from the actual product being handled. In this master thesis, the product is iron ore which is not a discrete

object and hence is not susceptible to carry RFID tags or similar. Consequently, the machine hauling the product during the process was interchanged as the smart product collecting data from the process.

- Some fields have potential improvements, such as to clarify misinterpretations, but also to measure the quality of the work the field covers and not only the extent, such as for data collection or similar. Further, some fields were thought to be too simplified for the assessment of digital readiness, such as digital modelling. For improving the assessment for these fields, more specific criteria are needed.

7.2 Contribution to the case company

To the case company, LKAB, the master thesis has contributed to several valuable insights. First, the identified key objectives provide LKAB with the information of where to focus its knowledge and expertise when going through the digital transformation. In addition to the major objectives identified, the analysis covers a detailed explanation and investigation for the readiness of each field within IMPULS.

Second, the outcome of the VPM resulted in a comprehensive illustration of the production loading and its activities. It was found that a similar illustration of the production loading did not exist at LKAB. Therefore, the illustration provided is thought to be of usage as a basis while discussing the procedures and potential improvements. In addition, the illustration is thought to be of great usage for introducing new personnel to the productional loading and giving them a simple illustration of how the process is performed.

Third and last, the usage of IMPULS resulted in an assessment of the digital readiness at LKAB. The assessment, both through a questionnaire, and from interviews and observations, is thought to be of great usage for LKAB since it is an external check of their progress in the digital transformation. While this master thesis focused on *production loading*, the same procedure is encouraged for other production processes at LKAB.

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APPENDICES

Appendix A. Thorough explanation of fields

This appendix contains a more explicit explanation of each of the fields used in the questionnaire, i.e., the fields within the dimensions of *smart factory*, *smart operations*, *smart products* and *employees*. For most fields, the interpretation is supported by the authors of IMPULS or that the interpretation of the field is seen as common knowledge. However, there are a number of fields that have proven difficult to define, these are interpreted by the authors of this master thesis themselves.

Smart factory

Equipment infrastructure (current) measures the extent of using machines and systems that can be controlled through IT. Additionally, the equipment infrastructure is evaluated on the interoperability and integration both between IT and machines, and between machine to machine. Interoperability is defined as *"the ability for a device from one manufacturer to work with one from another"* according to Gartner IT glossary. Further, integration according to Gartner IT glossary is defined as *"... detailed design and implementation services that link application functionality (custom software or package software) and/or data with each other or with the established or planned IT infrastructure. ...".* With other words, integration is the process to connect different IT sub-systems into one system.

Equipment infrastructure (target) is measured upon the extent the machines and systems can be *upgraded*. Meaning if the machines and systems can be upgraded to meet future demands, or they are needed to be exchanged. Machines and systems that are able to be connected with new modules and systems without replacing the existing resources are interoperable and integrated, and defined as able to be upgraded.

Digital modelling is the procedure of testing the success of a design or a solution to a problem through digital solutions. Examples of digital modelling are CAD/CAM/CAE but also simulations from data to answer questions on how to optimise production flow etc. Lichtblau et al. (2015) defines digital modelling as *"A digital model is composed of product-related data supplemented by transaction data, geopositioning data, and other data.".* The evaluation of digital modelling ranges from no digital modelling used, to complete digital modelling possible.

Data collection is the process of collecting digital data, both manual and automatically. Data collection analogue gives no score in this field.

Data usage evaluates how the data is collected and used, manual calculations or automatic and for transparency or optimization. Also, the amount of the data collected are actually used is evaluated.

IT systems measure the way IT systems are used within the company. Ranging from that IT systems are used to support main business areas to IT systems supporting all areas in the company. Also, IT systems are measured on its integration within the company, meaning the extent to which IT sub-systems within the company that is connected into one IT system.

Smart Operations

System-integrated information sharing is to integrate information in systems to make data accessible for all relevant persons to check, change or analyse. It evaluates the extent of information that is shared throughout the company with the use of IT systems. Meaning, if information is shared by one division within an IT system, and another division can access the information without manual handling and use it efficiently with its systems, the information sharing is thought of as system integrated. Further, the field is evaluated on the extent of both internal and external information sharing.

Autonomously guided workpieces can gather data on itself and its surroundings and communicate the data with IT systems to enable the workpiece to be guided through the processes autonomously. (Lichtblau et al., 2015, p.13). The field is evaluated on the extent of using autonomously guided workpieces, ranging from not in use at all to use in selected areas or even cross-enterprise.

Self-reacting processes are processes that use the data collected from smart products, meaning products that gather data on itself and its surroundings, to identify what to be performed next and initiate that production process autonomously. (Lichtblau et al., 2015) The evaluation of the field ranges from self-reacting processes not in use to them being used in selected areas or even cross-enterprise.

IT security relates to the extent of securing data and processes from breaches. Ranging from no IT security solutions implemented to comprehensive IT solutions being implemented in all relevant areas.

Cloud usage is a computing model providing resources such as data storage, applications and services through an on-demand network normally accessed from a provider (Mell & Grance, 2011). Cloud computing, or cloud usage, can be useful in achieving various business goals. It can be used for test and development environments, big data analytics, cloud storage and data backup (IBM Cloud, 2020).

Smart Products

ICT add-on functionalities are the sensors, or systems, that gives a smart product the ability to collect data on itself and its surroundings. A smart product is a physical object produced in the manufacturing process which also contains ICT add-on functionalities to communicate its progress in the manufacturing process or to collect data on itself and its surroundings. (Lichtblau et al., 2015) The evaluation ranges from no add-on functionalities available, to products featuring extensive add-on functionalities.

Use of data is a field related to evaluating the extent of data that is used for creating valuable information, transparency, analysis or steering processes etc. The actual usage of smart products can vary depending on the business sector. The levels are ranging from no data collected, to data being analysed and used.

Employees

Employee skills evaluates the extent of relevant skills present within the company. Skills can relate to strategic competencies such as IT, automation or digital transformation, but also the competences to operate machines in production or perform daily tasks. The highest achievable level for the field employee skills is described *"employees possess all necessary skills in several relevant areas"*.

Appendix B. Questionnaire

The questionnaire is presented in this appendix. The questionnaire was sent in Swedish to all respondents except for one, who received it in English. The questionnaire is presented in the English version in this appendix due to the master thesis being written in English. Both versions of the questionnaire had the same information and formulations.

Questionnaire of LKAB's Digital Maturity

This questionnaire is conducted within the framework of a master thesis with the aim of investigating LKAB's digital maturity. LKAB has several projects active to digitalize and develop its operations, such a change is difficult. This questionnaire is the basis for assessing where LKAB is today, to guide future development.

*Obligatorisk

What is your position? For example, production manager or head of department. *

Ditt svar

What do you think of when you hear digitalization?

Ditt svar

Do you know the concept of Industry 4.0 and / or are you actively working to implement it in your business area?

- ◯ Yes
- ◯ No
- ◯ Övrigt: ____

Smart factory

The smart factory is intelligent and interconnected, where production systems communicate with overall IT systems and smart products.

Please answer the questions below by choosing the highest level at which you meet the requirements.

How is the current equipment infrastructure integrated and controlled? *

- ◯ Level 0: No integration. Machine and system infrastructure cannot be controlled through IT
- ◯ Level 1: Some machines can be controlled through IT, are interoperable, or have Machine to Machine capability
- ◯ Level 2: Machine and system infrastructure can be controlled to some extent through IT, is interoperable or integrated
- ◯ Level 3: Machine and system infrastructure can be controlled through IT and is partially integrated
- ◯ Level 4: Machinery can be controlled completely through IT, is partially integrated or interoperable
- ◯ Level 5: Machines and systems can be controlled almost completely through IT and are fully integrated
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

What is the potential for upgrading the equipment infrastructure? *

- ◯ Level 0: Machines and systems cannot be upgraded
- ◯ Level 1: Future requirements for machines and systems are relevant
- ◯ Level 2: Some machines and systems can be upgraded
- ◯ Level 3: All machines and systems can be upgraded
- ◯ Level 4: Machines already meet some of the requirements or can be upgraded
- ◯ Level 5: Machines and systems already meet all future requirements
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using Digital modeling? *

- ◯ Level 0: No digital modeling
- ◯ Level 2: Some digital modeling
- ◯ Level 5: Complete digital modeling possible
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you collecting data from production? *

- ◯ Level 0: No data is collected
- ◯ Level 2: Data is collected but for the most part manually
- ◯ Level 3: The relevant data is collected digitally in certain areas
- ◯ Level 4: Comprehensive digital data collection in multiple areas
- ◯ Level 5: Comprehensive, automated, digital data collection in all areas
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using data from production? *

- ◯ Level 0: No data available for further use
- ◯ Level 2: Data is used for a few select purposes (greater transparency, etc.)
- ◯ Level 3: Some data used to optimize processes (predictive maintenance, etc.)
- ◯ Level 4: Data used in several areas for optimization
- ◯ Level 5: Data used for comprehensive process optimization
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using IT-system to support production? *

- Level 0: No support through IT systems
- Level 1: Main process supported by IT systems
- Level 2: Some areas of the business are supported by IT systems and integrated
- Level 3: Some areas of the business are supported by IT systems and integrated with one another
- Level 4: Complete IT support of processes, full integration
- Level 5: IT systems support all company processes and are integrated
- Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

What do you experience as the main challenges associated with the implementation of the "smart factory"?

Ditt svar

Smart operations

Smart operation is the integration of physical and digital systems, both within companies, but also between. Access to large amounts of data enables a new type of control of production, which requires less and less human control. This section measures how smart your general operation is.

Please answer the questions below by choosing the highest level at which you meet the requirements.

To what extent do you have integrated information sharing? *

- ◯ Level 0: No system-integrated information sharing
- ◯ Level 1: Beginnings of in-company, system-integrated information sharing
- ◯ Level 2: In-company information sharing partially system-integrated
- ◯ Level 3: Some in-company and beginnings of external system-integrated information sharing
- ◯ Level 4: Predominantly in-company and partially external system-integrated information sharing
- ◯ Level 5: Comprehensive in-company and partially external system-integrated information sharing
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using autonomously guided workpieces? *

- ◯ Level 0: Autonomously guided workpieces not in use
- ◯ Level 4: Experiments in test and pilot phase
- ◯ Level 5: Use in selected areas or even cross-enterprise
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using self-reacting processes? *

- ◯ Level 0: Self-reacting processes not in use
- ◯ Level 4: Experiments in test and pilot phase
- ◯ Level 5: Use in selected areas or even cross-enterprise
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

What is your degree of IT security? *

- ◯ Level 0: No IT security solutions in development or implemented
- ◯ Level 1: Initial IT security solutions planned
- ◯ Level 2: Multiple IT security solutions are planned or initial solutions are in development
- ◯ Level 3: IT security solutions have been partially implemented
- ◯ Level 4: Comprehensive IT security solutions have been implemented, existing gaps are being closed
- ◯ Level 5: IT security solutions have been implemented for all relevant areas
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using cloud solutions? *

- ◯ Level 0: Cloud solutions not in use
- ◯ Level 3: Initial solutions planned for cloud-based software, data storage, and data analysis
- ◯ Level 4: Initial solutions implemented
- ◯ Level 5: Multiple solutions implemented
- ◯ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

What do you experience as the main challenges associated with the implementation of the "smart operations"?

Ditt svar

Smart products

Smart products are equipped with ICT components (sensors, RFID, communication interfaces, etc.) that collect data about the production environment and report their own status. In this dimension, the products' ability to communicate is measured during the different stages of their production.

Please answer the questions below by choosing the highest level at which you meet the requirements.

To what extent do you use ICT add-on functionalities? (e.g. Product memory, self-reporting, integration, localization, assistance systems, monitoring, object information, or automatic identification) *

- Level 0: No add-on functionalities
- Level 1: Products show first signs of add-on functionalities
- Level 2: Products feature initial add-on functionalities
- Level 3: Products feature multiple, interrelated add-on functionalities
- Level 4: Products feature add-on functionalities in different areas
- Level 5: Products feature extensive add-on functionalities
- Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

To what extent are you using the data collected? (e.g. use of data for product development, sales support, after-sales) *

- Level 0: No data collected
- Level 2: Data collected but not analyzed/used
- Level 3: Data analyzed/used
- Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

Employees

The changes taking place in the workplace during the digital transformation have a strong impact on the company's employees, who must adapt to these changes and develop new skills. Companies undergoing the digital transformation must ensure that their staff is prepared for such a transformation by offering appropriate training.

Please answer the questions below by choosing the highest level at which you have met the requirements.

What level of competence do your employees currently possess in digitalization processes? *

- ○ Level 0: No skills
- ○ Level 1: Employees have low skill levels in one relevant area
- ○ Level 2: Employees have low skill levels in a few relevant areas
- ○ Level 3: Employees have adequate skill levels in some relevant areas
- ○ Level 4: Employees have adequate skill levels in several relevant areas
- ○ Level 5: Employees possess all necessary skills in several relevant areas
- ○ Does not have sufficient knowledge to give answers.

Do you want to clarify or elaborate on anything in connection to question above?

Ditt svar

Appendix C. Interview Questions

The questions used as a basis for the different interviews are presented in this appendix. However, it should be clarified that these questions were used as a pillar to direct the focus of the interview. Additional follow-up questions were asked depending on the answers.

Interview with IT

Kartläggning

Vi kommer att visa ett flödesdiagram av lastnings-processen. Den är tänkt att fungera som ett verktyg där vi tillsammans kan navigera oss för att identifiera problem. Detta flödesdiagram är skapat utifrån arkivanalys och det hade därför varit önskvärt om du kunde verifiera den. Vi anser att den är rörig att skicka i förhand, och därför kommer du att få se den först imorgon.

- Vilka av era tillgångar är uppkopplade?
- Vilka processer samlas det in information ifrån? Datainsamling. Hur görs denna insamling?

Datainsamling

- Manuell analog datainsamling (Operatör skriver aktivt in data i loggbok eller liknande)
- Manuell digital datainsamling (Operatör behöver aktivt skriva in data så att det hamnar i IT system)
- Automatisk digital datainsamling (Operatör är passiv och data samlas in automatiskt till IT system genom digitala teknologier som sensorer på maskiner såväl som på operatörer/arbetare)
- Vilka steg av lastningen samlas data in automatiskt/manuellt?
    - Hur samlas den?
    - Vad för data samlas in?
    - Vad används den insamlade datan från de olika stegen i lastningen till?
- Samlas data in i huvudsak manuellt eller automatiskt i lastningen, kan du ge någon uppskattning på procentsats? Ex. från maskiner, operatörer, eller andra arbetare
    - Hur mycket av den data som samlas in används och tas till vara på?
        - Kan du ge exempel på bra, och mindre bra exempel på hur data används?
        - Av den data som samlas in, analyseras den manuellt eller automatiskt?
        - Kan datainsamlingen användas på ett bättre och mer effektivt sätt? Hur?
            - Vad för data vore bra att ytterligare samla in? Är den datainsamlingen ekonomiskt försvarbar?
- Delar ni information till andra avdelningar inom LKAB, exempelvis förädling eller logistik.
- Finns det något behov eller någon fördel för det?

IT-system

- Vilka IT system används i lastningen idag?
    - Är de molnbaserade, ja eller nej?
    - Hur stödjer dessa IT-system lastningen idag? Vilka funktioner har ni idag?
        - Stödjer dessa system andra delar av verksamheten? (gruvprocesser, förädling, logistik)
        - Vem har tillgång till informationen i dessa IT-system? Ex. andra delar av produktionen, organisationen, leverantörer och kunder?
- Vilka funktioner skulle du vilja se i framtida IT-system?
    - Stödjer dessa system andra delar av verksamheten? (gruvprocesser, förädling, logistik)
    - Vad för funktioner tror du kan ha störst inverkan på att förbättra effektivitet i produktionen?
    - Vad för funktioner tror du kan ha störst inverkan på att förbättra arbetsmiljön i produktionen och runtom?

Uppkopplade system och automation

- Hur väl vill du påstå att samspelet IT-systemet mellan maskiner och IT-system sker idag?
    - Kan du ge exempel för hur de samverkar i flera nivåer (interoperable)
        - Kan de olika systemen utbyta och dra nytta av information från varandra?

Avslutande frågor

- Vilken kunskap tycker du att medarbetare på LKAB har när det kommer till kompetens inom digitalisering och automation, finns kompetensen?
- Vad tycker du om den digitalisering som LKAB genomgår, och har genomgått, när det kommer till IT-system, automatisering, med mera.
- Vad skulle du vilja se för förändring på LKAB den närmsta tiden?

För problem, identifiera:

- Konsekvenser av problemet.
- Orsaker till problemet.
    - Vilka är mest betydelsefulla orsaker enligt dig.
- Hur åtgärdas problem idag?
- Vad kan vara förebyggande åtgärder för att problemet inte ska uppstå?
    - Varför tror du att de här åtgärderna inte har tagits, vilka svårigheter finns med att lösa det här problemet

Interview with Automation

Vi kommer att visa ett flödesdiagram av lastnings-processen. Den är tänkt att fungera som ett verktyg där vi tillsammans kan navigera oss för att identifiera problem. Detta flödesdiagram är skapat utifrån arkivanalys och det hade därför varit önskvärt om du kunde verifiera den. Vi anser att den är rörig att skicka i förhand, och därför kommer du att få se den först imorgon.

- Är det någon aktivitet som fattas eller är ordningen felaktig?
- Finns det fler beslutssteg eller andra viktiga faktorer vi har missat här?

Automatisering kopplat till flödesdiagrammet.

- Vilka är drivkrafterna bakom automatisering i gruvan?
- Vilka moment/maskiner som är helt, delvis eller inte alls automatiserade? Koppla gärna dessa till de olika momenten som visas i flödeskartan.
  - Vad finns det för för- och nackdelar med automatiseringen av dessa moment?
    - Vad finns det för för- och nackdelar med automatisering i allmänt i gruvan?
  - Är det någonstans i lastningen du skulle vilja se mer automatisering?
    - Vilka delar av processen är avsedda att bli automatiserade?
- Vilka av era tillgångar är uppkopplade?
- Vilka delar samlas det in information ifrån? Datainsamling. Till vilka system görs denna insamling, och görs den manuellt av operatör eller automatiskt?
  - Ex. från era lastare. Data som operatör skriver in själv, med mera.
  - Vilken av dessa data analyseras, och kommer till användning?

- Vilken grad av automation anser ni er ha och vilken grad planerar ni att ha på era lastmaskiner?
  - Vilka funktioner i lastmaskinerna är autonoma?
    - Bara operationer och statusuppdateringar eller kan den också planera sin rutt och sekvens i processen?
- Kan de olika systemen utbyta och dra nytta av information från varandra?
  - Ex. Kan en Epiroc-maskin tala med en Sandvik-maskin.
  - Vilka åtgärder görs för att detta ska vara möjligt?
- Hur samverkar IT och automation?

Identifiera problem, som X utifrån sitt perspektiv, har sett

- Vad är det för problem som kan uppstå i produktionen, som ni önskar lösa med hjälp av gruvautomation?
  - Om det är många, kan du nämna och berätta om de som förekommer mest frekvent?
  - Vilka har största konsekvenser för produktionen?
  - Är det något problem som kan få produktionen att bli ståendes en längre tid utan möjlighet att utföra sina arbetsuppgifter?
- Har du tänkt på några förbättringsmöjligheter med automation?

För problem, identifiera:

- Konsekvenser av problemet.
- Orsaker till problemet.
  - Vilka är mest betydelsefulla orsaker enligt dig.
- Hur åtgärdas problem idag?
- Vad kan vara förebyggande åtgärder för att problemet inte ska uppstå?
  - Varför tror du att de här åtgärderna inte har tagits, vilka svårigheter finns med att lösa det här problemet?

Avslutande frågor

- Vilken kunskap tycker du att medarbetare på LKAB har när det kommer till kompetens inom digitalisering och automation, finns kompetensen?
- Vad tycker du om den digitalisering som LKAB genomgår, och har genomgått, när det kommer till IT-system, automatisering, med mera.
- Vad skulle du vilja se för förändring på LKAB den närmsta tiden?

Interviews with Mine Planning

For the interviews with mine planning, two separate interviews were performed. This is why there is two separate questionaries for these interviews, one in Swedish and the other one in English.

Vi kommer att visa ett flödesdiagram av lastnings-processen. Den är tänkt att fungera som ett verktyg där vi tillsammans kan navigera oss för att identifiera problem. Detta flödesdiagram är skapat utifrån arkivanalys och det hade därför varit önskvärt om du kunde verifiera den. Vi anser att den är rörig att skicka i förhand, och därför kommer du att få se den först imorgon.

- Är det någon aktivitet som fattas eller är ordningen felaktig?
- Finns det fler beslutssteg eller andra viktiga faktorer vi har missat här?
- Vilka information/datainsamling används som beslutsstöd för planering?
    - I vilka aktiviteter samlas den datan in?

Planering inför

- Hur tycker du att planeringen fungerar idag? Vad fungerar bra, mindre bra?
    - Är planeringen i huvudsak manuell eller automatisk analys?
        - Ge exempel.
    - Vilka parametrar, variabler, använder ni i planeringen idag för att förutspå?
        - Vilka parametrar skulle du vilja kunna använda dig av för att ge en bättre prognos?
            - Ex. transporttid till ore pass, underhållsarbete, öppna ore pass etc. "*Predictive maintenance*".
        - Vad skulle du vilja se för lösningar för att planeringen skulle fungera bättre?

Planering uppföljning

- Hur fungerar er uppföljning av planering? Verifierar ni er planering, och omarbetar kontinuerligt, hur fungerar det?
    - Görs den uppföljning helt och hållet genom analys av en person, eller kan den göras automatiskt och generera konkreta förslag till er?
        - Om manuell av person, tror du det skulle kunna vara möjligt att göra den automatiskt och generera konkreta förslag? Vad hindrar det från att bli möjligt?
        - Om det redan görs automatiskt, berätta hur det görs. Är ni nöjda med lösningen?

Planering för underhåll

- Har ni någon planering för underhåll, eller uppskattningar för olika problem som kan uppstå i gruvan. Kan du ge exempel?
    - Underhållsarbete kan påverka produktiviteten stort.
- Kan du tänka på någon parameter, eller aktivitet, som kan ha stor effekt på planeringen som vore bra att mäta och har i åtanke?

Beslutsstöd

- Använder sig lastningen av någon typ av beslutsstöd?
    - Ex. så använder ni våg som avgör malmhalt för att veta när ni ska stanna. Har ni något mer sådant här automatiskt, eller digitalt, stödprogram?
    - "dynamisk lastning"
- Görs någon sådan här typ av analys i realtid?

Driftstopp

- Upplever du att ni ofta har driftstopp, hur ofta kan det vara?
    - Var beror dessa på i stort, går det att kategorisera dem?
        - Vilka är mest betydande (längst)?
        - Vad beror det på?

IT-system

- Är det någon av dina arbetsuppgifter som hade kunnat förenklas genom någon lösning med smidigare kommunikation, bättre informationssystem eller tydligare visualiseringar. Kan du ge exempel.

Avslutande

- Vilken kunskap tycker du att medarbetare på LKAB har när det kommer till kompetens inom digitalisering och automation, finns kompetensen?
- Vad tycker du om den digitalisering som LKAB genomgår, och har genomgått, när det kommer till IT-system, automatisering, med mera.

(Draw control strategy optimization, ground support and production planning)

- The decision to stop loading from a drawpoint and proceed to the next one in the loading process. How is this performed today? Is there any draw control strategy? Is it the same as from your paper *Draw control strategy for sublevel caving mines*
    - We have heard that there is work in development with something called "dynamic loading". Can you describe it for us?
        - What data is it that is thought to be collected?
            - E.g. current global price for iron, volume and weight analysis, data from previous loadings above, AI scanning the rocks, transportation distance.
        - Will the data be analysed manually or automatic, meaning is there any human interaction for the analysis to be performed?

IT-system

- In what other parts of the loading is data collected and then analyzed?
- Can you find any additional potential for digitalisation in the loading process?
    - Examples.
- How much of the data collected is used and utilised?
    - Can you give examples of good, and less good examples of how data is used?
    - Of the data collected, is it analyzed manually or automatically?
- Is it any of your tasks that could have been simplified by any solution with smoother communication, better information systems or clearer visualizations. Can you give examples?

Connected systems and automation

- How well would you say that the interaction of the IT system between machines and IT systems takes place today?
    - Can you give examples of how they interact in several levels (interoperable)
        - Can the different systems exchange and benefit from information from each other?

Decision support

- Does the loading use any type of decision support, in addition to discussed earlier?
    - Is any kind of analysis done in real time?

Additional questions

- What ERP system are you using?
    - Classification of Giron, data management or how would you explain?
- Are there any additional IT-systems in use?

Concluding

- What knowledge do you think employees at LKAB have when it comes to competence in digitization and automation, does the competence achieve an appropriate level?
- What do you think about the digitization projects that LKAB is undergoing, and has implemented, when it comes to IT systems, automation, and more?
- What would you like to see for change at LKAB in the near future?

Interview with Production managers and Operator

The interviews with two production managers and one operator were held as a joint interview. Hence, one questionnaire is appended for this interview.

Kan ni berätta om er roll som produktionschef, vad gör ni i ert arbete?

Flödesdiagram

Vi kommer att visa ett flödesdiagram av lastnings-processen. Den är tänkt att fungera som ett verktyg där vi tillsammans kan navigera oss för att identifiera problem. Detta flödesdiagram är skapat utifrån arkivanalys och intervjuer, det hade därför varit önskvärt om du kunde verifiera den.

- Är det någon aktivitet som fattas eller är ordningen felaktig?
- Vilket steg är mest problematiskt, eller uppstår övervägande problem med?

Vi har en del specifika funderingar som vi har samlat på oss igenom arbetet, som ni gärna får förtydliga för oss.

1. Hur blir ni informerade om var lastning ska ge under dagen? Hur blir operatörerna informerade om var de ska lasta under dagen? Hur kommuniceras det ifall det här förändras? Fungerar något bra, mindre bra?
2. Vad är det för praktisk skillnad på *manuell* och *automatiserad LHD*, vilka delar är autonoma, vilka är fjärrstyrda? Görs allting manuellt på manuell lastare?
    - Lastning, transporten, dumpning
    - Hur navigerar de sig? Konfirmera hur de kommunicerar.
3. Hur ser ni på fördelar, och nackdelarna med att använda manuell eller fjärrstyrd/automatiskt? Vad är de stora för- och nackdelarna?
    - Vad har automatiska för nackdelar, problem med media?
    - Vilken typ brukar medföra problem oftare? (Underhåll, system som lägger av etc.)
4. Berätta om hur operatörernas dagliga tillsyn, hur görs den? Gör operatörerna det när de kommer?
    - Är det ofta det uppstår problem i samband med kontrollen, att något behöver åtgärdas som medför stillestånd?
    - Hur rapporteras fel?
5. Om en för stor sten fastnar i schaktet och behöver tas undan för att sprängas, hur ofta händer det, kan ni berätta mer om hur det går till, asså vem kontaktar man och så?
6. Är det någon del i lastningen som är extra problematisk, eller som ofta medför stillestånd som minskar produktionen?
7. Följer lastare dynamic loading, vad tycker dem om det?

Typiska problem som uppstår

1. **Kan du ge exempel på problem som har en negativ effekt på produktionen?**
    - Om det är många, kan du nämna och berätta om de som förekommer mest frekvent?
    - Vilka har största konsekvenser för produktionen?
    - Är det något problem som kan få produktionen att bli ståendes en längre tid utan möjlighet att utföra dina arbetsuppgifter?
2. Har du tänkt på några förbättringsmöjligheter kopplat till din arbetssituation eller produktionen, vad har det varit?

För problem, identifiera:

- Konsekvenser av problemet.
- Orsaker till problemet.
    - Vilka är mest betydelsefulla orsaker enligt dig.
- Hur åtgärdas problem idag?
- Vad kan vara förebyggande åtgärder för att problemet inte ska uppstå?
    - Varför tror du att de här åtgärderna inte har tagits, vilka svårigheter finns med att lösa det här problemet?

Specifika frågor kopplade till driftstopp och underhåll

1. Upplever du att ni ofta har driftstopp, hur ofta kan det vara?
    - Var beror dessa på i stort, går det att kategorisera dem?
        - Vilka tar längst tid, är det något som tar onödigt lång tid?
        - Vad beror det på?
2. Om person kommer i kontakt med underhåll:
    - Hur fungerar samarbetet med underhåll?
        - *Hur arbetas det med för att minimera tiden maskiner behöver underhåll?*
        - Hur fungerar kommunikationen? Ledtider.
3. Hur påverkar det arbetet om ni inte uppnår rätt tonnage i månaden?

Åsikter om IT-system, allmänt

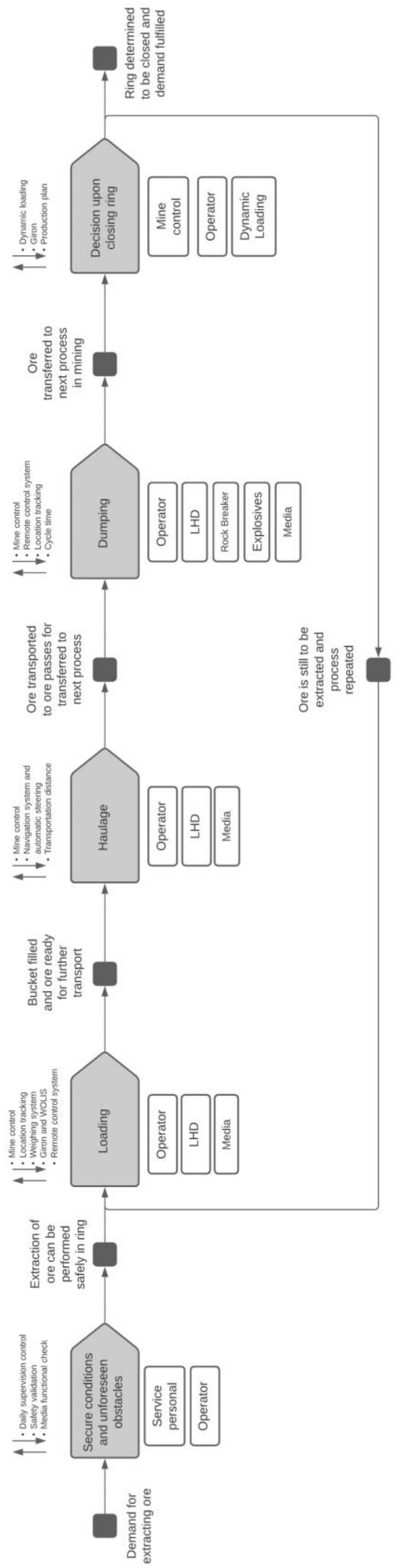
1. Vilka stödjande IT-system använder du kopplat till din vardag? (Wolis, GIRON)
    - Vilka är bra, mindre bra? Varför?
    - **Vad önskar du att du mer kunde få ut från IT-system eller mobil.**
2. Ser du någon speciell förbättringspotential där ny teknik potentiellt kan användas?
    - Information- och kommunikationsförbättringar
    - Tydligare visualiseringar

Avslutande frågor

1. Vilken kunskap har *medarbetare* på LKAB har när det kommer till **kompetens** inom digitalisering och automation, finns **kompetensen**? Hur utvecklas den kompetensen, utbildningar etc? HR håller i utbildningar?

Appendix D. VPM of Production Loading

In this appendix, the VPM of the activities within the sub-process "production loading" is shown.



Appendix E. Search Strings used for the literature study

In this appendix, the search strings used for the literature study are presented.

Search String
Digitalization
Digital Transformation
Business Process Digitalization
Business Process Transformation
Process Management
Business Process Management
Manufacturing Digital Transformation
Digital Business Strategy
Digital Alignment
Digital Resilience
Manufacturing Digitalization
Mining Digital Transformation
Mining Digitalization
Process Mapping
Process Mapping Digitalization
Process Mapping IT
Industry 4.0
Digital Maturity
Industry 4.0 Maturity Model
Digital Maturity Production Processes
Digital Readiness