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Financial and Operational outcomes of a No-Code Manufacturing Execution System (MES)

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Abstract

Purpose: This study aims to identify the operational and financial outcomes of companies implementing the no-code manufacturing execution system (MES).

Methods: This study has been conducted using inductive reasoning to develop new theories in this unexplored subject. The thesis has conducted a multiple case study to collect qualitative, empirical data. Qualitative data has been collected through conducting three interviews from two separate companies. The Research Background and Findings section was then cross analyzed to find commonalities to form conclusions.

Conclusion: Implementing a no-code MES offers operational and financial benefits for manufacturing companies. It improves productivity, reduces lead times, increases flexibility, and enhances quality efforts. Cost savings are achieved through paper reduction and lower implementation costs compared to traditional MES solutions, which do not have no-code features. Overall, a no-code MES delivers advantageous outcomes efficiently and eliminates the need for significant capital investments and technical skills.

Theoretical Contribution: This thesis contributes to the field of science by unifying Manufacturing Execution System (MES) with the existent subject of low-code/no-code. This study creates a deeper knowledge by merging science with empirics.

Practical Contribution: The thesis contributes to practitioners in the manufacturing industry by indicating the relevance and importance of the beneficial operational and financial outcomes of adopting a no-code MES. Firstly, there are strong indications that a no-code MES could be a possible solution for companies that could be impacted by the labor shortage in software developer jobs. Secondly, as the no-code MES mitigates the barriers with traditional MES solutions, having the MES built on no-code makes the solution more cost-effective and easy-to-maintain.

Limitations & Future Research: This study is limited to two case companies and three interviews. The study's findings are limited by the short duration of a no-code MES implementation in the case companies, preventing a full investigation of financial outcomes. Further research is necessary to fully examine the financial outcomes of implementing a no-code MES.

Keywords: *Manufacturing Execution System, Operational, Financial, Outcomes, Low-code, No-code, case study*

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1. Introduction

1.1 Background

The concept of Industry 4.0 was coined from an approach to encourage the manufacturing industry to take advantage of the opportunities with the increased development in information technology (IT), in Germany in the year 2011 (Bergman & Klefsjö, 2020). One part of the concept of Industry 4.0 is the development of smart manufacturing systems (Jaskó et al., 2020). Smart manufacturing systems are characterized by the integration of new technologies that enable rapid and widespread information flow within the manufacturing process and control. The effective collection and analysis of this large data to inform decision-making is a complex and dynamic process that requires optimized performance assurance measurement. Smart manufacturing can deliver manufacturing data in real-time and enhance unprecedented awareness, agility, productivity, and resilience in the production process (Kibira et al., 2016). Whilst, according to The Swedish Ministry of Enterprise and Innovation (2015) the smart industry is heavily digitalized, autonomous, and flexible to changing customer demands and needs.

As part of smart manufacturing, there is the development of Manufacturing Execution Systems (MES) (Bokhorst, et al., 2022). The MES is a category of industrial software for the shop floor and is used to manage and monitor manufacturing processes in industrial production (Manufacturing Enterprise Solutions Association [MESA], 1997a). The possible outcome of an implemented MES has increased quality and personnel productivity, reduced lead time, and reduction in energy consumption according to Kletti (2015, referred to in Chen & Voigt, 2020). In a report from the market research company MarketsandMarkets (2022), they predict that the MES market is expected to grow from 13.0 billion USD in 2022 to 20.0 billion USD by 2027. Which in other words is a compound annual growth rate of 9 %.

Traditional software development is complex and more often than not built using multiple frameworks, technologies, and libraries which can become costly and hard to manage. Furthermore, it is becoming increasingly hard to find technically qualified developers. Low-code and no-code (LCNC) development is a growing approach that lowers the skills required by eliminating most of the coding needed (Pinho et al., 2023). The research firm Gartner, predicts that low-code platforms will be used in 65% of software development by 2024 (Farish, 2020) and 70% by 2025 (Gartner, 2021). By utilizing LCNC capabilities, developers can prioritize their efforts on creating unique competitive features, rather than writing and reproducing standardized codes. The user-friendly technology facilitates fast project completion and testing, leaving more time for value creation (Turner, 2023).

Turner (2023) also explains that LCNC represents a paradigm shift for how users interact with softwares and that companies should embrace this technological development. As businesses face economic instability and high IT costs, numerous teams are encountering budget reductions. Nevertheless, as digital transformation persists to advance rapidly, it has become more critical for companies to prioritize both speed and excellence to fulfill the requirements and needs of customers. That's why LCNC can be a game changer because it can tackle the challenge concerning software development.

When Bhattacharyya & Kumar (2021) searched using the keyword “no-code Platforms” in the database “Scopus” they discovered that there were few academic articles about the subject. In the years between 2016 and 2019, there was only one published article about “no-code Platforms”. But in 2019 the number increased to three articles (Bhattacharyya & Kumar, 2021). When we search today in Scopus using the keyword “no-code platforms” we find 8 published academic articles in 2021 and 9 published in 2022. This indicates a rising interest in the field of no-code platforms.

MTEK is developing and offering a unique MES built on a no-code platform, which is called MBrain. Their customers include manufacturing companies all over the world. MBrain is an intuitive software that is easily adapted to the client’s processes thanks to the opportunities of no-code. MBrain enables traceability, data collection, integration of equipment, and complete digital control (mtek.se n.d). Testimonials about MBrain from their customers can be summarized as process-oriented, flexible, adaptive, and smooth implementation with quick value creation in support of the customers' continuous improvement efforts and Industry 4.0.

The effects and implications of an MES built upon a no-code platform are worth further research concerning the market growth rate of MES (MarketsandMarkets, 2022) and the increased academic interest in no-code (Bhattacharyya & Kumar, 2021) and the prediction that the majority of software in a near future will be based on LCNC (Gartner, 2021). Searching in the database Discovery for academic articles using the keywords “no-code” OR “no code” AND “MES” OR “manufacturing execution system” results in zero matches, thus indicating that the field of a combined MES developed on a no-code platform is underdeveloped. Because of the increased trend of MES and LCNC and the lack of research on this subject. This study will use a case company MTEK, to contribute new knowledge about the opportunities with a combined no-code MES system.

1.2 Purpose

This study aims to identify the operational and financial outcomes of companies implementing the no-code MES.

1.3 Research Questions

RQ1: What impacts do the no-code MES bring to manufacturing companies’ operations and finance?

RQ2: How do the no-code MES affect manufacturing companies’ operations and finance?

2. Methodology

2.1 Research Approach and Strategy

Streefkerk (2023) explains that when the studied field is underdeveloped and has limited knowledge, inductive research is required to develop theories. Induction is an approach that seeks to develop theories based on observations and conclusions (Säfsen & Gustavsson, 2019). No-code MES is an unexplored field hence an inductive approach has been adopted to be able to fulfill the purpose and develop new knowledge in the subject. Qualitative research gathers non-numerical data through text or audio, compared to quantitative research which is expressed in numerical values. Inductive reasoning is frequently associated with qualitative research. Qualitative research aims to comprehend concepts, thoughts, or experiences, enabling researchers to gather comprehensive insight into topics that lack clarity or understanding (Streefkerk, 2023). This study has been conducted using inductive reasoning with qualitative data-collection methods as the concept of no-code MES can not yet be described in numerical values and requires comprehension. See figure 1 for the research process and the underlying reasoning approach whilst conducting this thesis.

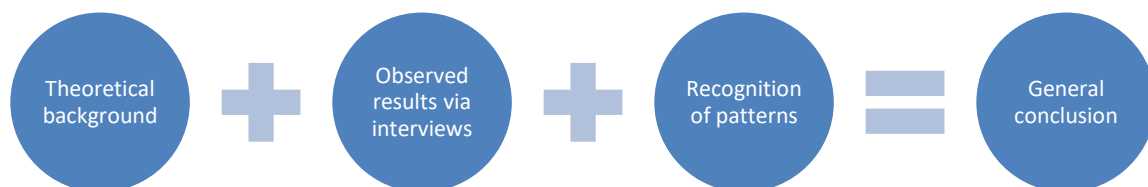


Figure 1: The research process and the scientific reasoning approach while conducting this thesis.

2.2 Research Design

In order to achieve an explanation for unexplored areas the research and its methods have to achieve high levels of flexibility, which the case study as a method promotes. Case studies are suitable when deeper knowledge about a less-known subject is sought because of its explorative nature. Using case studies can be of support in developing new theories or in refining already existing theories (Säfsen & Gustavsson, 2019). Because of the unexplored nature of MES built on a no-code platform, new knowledge is required to give an explanation which is why using case companies was deemed the most appropriate method. In a case study, single or multiple cases can be studied. The benefit of having multiple cases in a case study is that it increases the generalizability if the results are similar after comparing them (Säfsen & Gustavsson, 2019). In this study, we chose to do a multiple case study to answer our research questions on why, and how a no-code MES impacts a company's operational and financial performance. The case companies that we have studied are discrete manufacturing companies that use MTEKs' no-code MES (MBrain), see Table 7 for all the selection criteria.

Table 7: Selection criteria for the case companies.

Selection Criteria	Company 1	Company 2	Company 3	Company 4
Currently using MBrain	X	X	X	X
Manufacturing Company	X	X	X	X
Accessibility	X	X		X
Availability	X	X	X	

Companies 1 and 2 are both manufacturing companies that are currently using MBrain and are both accessible and available. Company 3 met all selection criteria but was not accessible since its facilities are located in the USA. Company 4 also met all selection criteria but did not have time or the means to participate in this study. The two companies that met the selection criteria in this study were selected and made sure that they have different characteristics. Company 1 has implemented MBrain in an already existing factory that used another MES solution prior to MBrain. Company 2 however adopted MBrain in multiple sites, the majority of which were implemented from the start of the production in the new factories with no other solution prior to MBrain. The mix of having case companies with different experiences in MES solutions should increase the generalizability of the findings in this thesis (chapter 4, will provide further explained information about the case companies). To maintain the focus on the actual purpose of this study, the anonymity of the companies will be ensured.

2.3 Data collection

2.3.1 Primary data and secondary data

Primary data can be collected in direct connection to the data source with the aim of being able to directly answer the research question/s of the study. Primary data can be results from measurements, observations, surveys, or interviews (Säfsten & Gustavsson, 2019). The primary data that were used in this thesis are retrieved from the individual interviews conducted with representatives from the case companies that use MBrain, see more in 2.3.2.

Secondary data is information that already exists and has been collected by someone else. If primary data has been collected for another purpose in another study, it includes secondary data for the external receiver (Säfsten & Gustavsson, 2019). The secondary data that has been used is business information obtained from the case companies' websites and information material provided by MTEK.

2.3.2 Interview

Interviews as a method can be used to collect people's experiences and perceptions and can therefore be a complement to observation to collect valuable primary data. An interview is a conversation with a clear purpose and some structure between the researcher and a respondent. The conversation is professional, and it is the researcher who leads the conversation. An interview can be either unstructured, semi-structured, or structured (Säfsten & Gustavsson, 2019). To be able to fulfill the purpose of this thesis, a semi-structured interview was decided as an appropriate method considering the author's lack of knowledge and experience about how MESs are used in practice. Existing academic literature about the field and secondary data from MTEK eased the construction of interview questions despite the lack of knowledge from the authors. The interviews were conducted individually with the representatives from the case companies and lasted between 25-60 minutes (see Table 8 for full information). Both authors were present and recorded each interview to make sure all information was gathered and interpreted correctly. Säfsten & Gustavsson (2019) argued that a semi-structured interview is when the overall questions are predetermined but the follow-up questions can be open-ended. The overall questions that were used during the interviews were related to *how they use MBrain as an MES solution, how they worked prior to adopting MBrain, and what differences that have affected them after implementing MBrain* (see Appendix 1 for the full interview questionnaire). One of the authors led the interview whilst the other author mainly took notes and provided relevant follow-up questions. Notes were made in case the recording turned out to be unsuccessful.

Table 8: The table presents information regarding how the interviews were conducted with representatives from the case companies.

Interviewee	Company	Role	Years of experience	Date	Length	Location
Respondent 1	Company 1	Site manager	22	24/04/23	60 min.	Kvänum
Respondent 2	Company 1	Operator	12	24/04/23	25 min.	Kvänum
Respondent 3	Company 2	Production development manager	7	04/05/23	35 min.	Solna

The respondents from the case companies that were included in this qualitative study were selected through the selection criteria in Table 9. After contact with the respondents, it was determined that three interviews were to be conducted to gain an acceptable amount of data. The last respondent (Operator at Company 2) could not participate which resulted in two separate interviews at Company 1, and one at Company 2.

Table 9: Selection criteria for the respondent of the interview.

Selection Criteria	Company 1 Production Development Manager	Company 1 Operator	Company 2 Site Manager	Company 2 Operator
Experience	X	X	X	X
Accessability	X	X	X	X
Availability	X	X	X	

2.4 Data Analysis

After the interviews were conducted, the recordings were transcribed using Microsoft Word's Transcription service. This enabled a quick and satisfactory transcription that the authors then analyzed manually by simultaneously listening to the interview to ensure that all information was included, and with the correct grammar. Importing the recording and getting it automatically transcribed took approximately 1 minute and the manual correction took approximately a total of 3 hours. The time it takes to transcribe the material would have likely been greater and still not have been any more accurate if we were to transcribe the material manually, compared to the used method. After the transcription, the authors categorized the information and removed the parts that could not be related to the study's purpose and research questions. The categorization was done according to which company the respondents belonged to (see Chapter 4, findings). In the analysis and discussion section, we compared what the two companies had in common related to how they utilize the no-code MES and what operational and financial outcomes it has resulted in, whilst relating it back to the existing field of MES and LCNC.

2.5 Method Reflection

Reliability refers to the fact that the study should be possible to repeat and get the same result, which implies that the method should be dependable. If the interview is being recorded the respondent can be emotionally affected, which results in low reliability (Säfsten & Gustavsson, 2019). To avoid any tense situations the atmosphere was relaxed, and the interviews were conducted in a calm manner. The respondents were also informed about the purpose of the recording and that all recorded material was to be destroyed after the transcription to minimize the impact on the reliability of the study. The fact that both authors recorded all interviews entails a risk that the respondents may have subconsciously been affected negatively on the reliability compared to if only one of the authors were recording (or not recorded at all). There were no obvious signs that the respondents were affected by the decision to record the interviews as there were no objections, but highlighting the risk in doing so is important. However, it was beneficial during the transcription to have the collected material from the interviews in two separate recordings in case the quality of one recording got compromised.

Säfsten & Gustavsson (2019) concludes that validity refers to whether the investigated phenomena is accurate and appropriate and if the conclusions drawn can be generalized. According to Säfsten & Gustavsson (2019) validity is about whether you can generalize your investigation. To ensure that the collected data in this thesis was accurate and appropriate the authors read about MBrain provided by MTEK to get an understanding of how their no-code MES is built and can be used by their customers. In order to ensure the relevance of the interview proposal for the purpose of this thesis, existing literature on both MES and no-code was collected before the interview proposal was created. The authors also got feedback on the interview proposal from the supervisor prior to conducting the interviews. The supervisor's feedback was valuable as it involved an additional person reviewing the proposal, in addition to the authors, to ensure the questions were relevant and could be used to fulfill the thesis' purpose. The supervisors support in continuously reviewing the collected material as well as the analysis to ensure relevancy and that no bias was present. This review from an independent third-party proved to be an important measure as both authors have been employed as summer interns at MTEK. The fact that both authors have some experience from the no-code MES facilitated the conduction of this thesis as the understanding of the solution gained from the internship proved to be advantageous. This made it possible to compose a relevant interview proposal which proved to achieve the insights needed to fulfill the purpose of the thesis.

As there were great distances to travel to the case companies, the project incurred consumption of both time and costs to attend the interviews. To mitigate the negative effects, we could have conducted the interviews digitally instead, for example via Zoom or Microsoft Teams. On the other hand, in doing so, there might have been an impact on the amount and quality of information that was retrieved during the interviews, as Foscarini et al. (2022) concluded that virtual meetings tend to result in a reduction in user attention from the participants compared to physical meetings.

2.6 Ethical Approach

This study has followed Good Research Practice to ensure a good ethical approach was attained during the whole process of this thesis. Good Research Practice consists of four ethical principles that need to be considered to ensure that no negative consequences arise from conducting the research. The four ethical principles are requirements related to information, consent, confidentiality, and utilization (translated from Vetenskapsrådet, 2002).

To make sure that no ethical conflicts would occur, all parties were firmly informed that the sole purpose of the study is for research purposes only. Further, did the authors inform the participants that it is voluntary and that they had the right to cancel their participation at any time, and that the recordings were to be destroyed after the transcription. Furthermore, the authors made sure that every party (Company, Respondent) gave their consent to participate, both verbally before each interview and written through the initial contact. The authors made sure that no information included in this study meant no harm in publishing confidential information that might harm the companies or any other third-party competitiveness. These measures are adequate to ensure that the thesis follows Good Research Practice and does not contribute to any negative consequences for the participants while conducting the study.

3. Theory Background

There is currently no literature about a combined no-code MES in the existing literature. In order to fully understand how a no-code MES improves production performance, it is essential to explore the existing literature about the concepts of MES and LCNC, separately. I4.0 is tightly connected with the structure and functionalities in an MES, therefore existing literature on I.4 has been examined. The existing literature available regarding these concepts has been summarized in the following sections. The no-code MES solution, MBrain, that was used to conduct this thesis is developed by the Swedish company MTEK.

Table 1 presents the search strings of the literature in MES, LCNC, and the combination of both subjects. There is currently no existing literature in the field of MES and no-code in combination. The table also illustrates which criteria and keywords that were used during the selection process of the academic articles.

Table 1: Searching scheme.

Keywords	Database	Number of search results	Selection criteria	Used reports	Source
“Manufacturing Execution System” OR MES	Discovery	81 603	Peer-reviewed, MES functionality and the expected outcomes.	8	Shojaeinasab et al., 2022; Chen & Voigt 2020; Jaskó et al. 2020; MESA 1997a; MESA 1997b; Kletti, 2007; Chhor et al., 2022; Kritzinger, 2018.
No-code OR low-code OR no code OR low code AND platform	Discovery	7 942	Peer-reviewed, LCNC usability in the manufacturing industry and digitalized processes	5	Chhor et al., 2021; Pinho et al., 2023; Bhattacharya & Kumar, 2021; Farish, 2020; Sanchis et al., 2020; NIC, n.d.
No-code AND “Manufacturing Execution System” OR MES	Discovery	0		0	

3.1 Industry 4.0

The fourth industrial revolution (I4.0) represents the usage of Smart Cyber-Physical Systems (CPS) that connects the virtual and physical production environment in order to achieve improved efficiency, and product and service quality. The integration of the virtual and physical environment can be achieved by utilizing digital technology such as connecting devices via Internet of Things (IoT), big data, digital twins (DT), and cloud computing in addition to Artificial Intelligence (AI) (ElMaraghy et al. 2021). I4.0 aims to create a “smart manufacturing industry” by integrating smart devices and machines and utilizing machine learning to facilitate communication and intelligence between them (Iqbal et al., 2022). Smart manufacturing can be defined as a part of the introduction of new technology that promotes an efficient flow of information within the manufacturing system. Smart manufacturing can result in a high level of operational performance such as agility, productivity, unprecedented awareness, resilience, and real-time data from sources in the production environment (Kibira et al., 2016). According to Guo & Xu (2021) can the utilization of digital technologies has a positive, and lasting impact on the process-based operating performance of firms. The study also found that there was a U-shaped correlation between the adoption of digital technologies and financial performance, indicating that firms need to expect a two-to-four-year period before profits are realized.

3.2 Manufacturing Execution System (MES)

3.2.1 The background of MES and its functionalities

MES is a system that started to develop from the inability of Enterprise Resource Planning (ERP) and Material Requirement Planning (MRP) systems to handle the operations requirements in manufacturing. The manufacturing facilities required detailed information of the production status in real-time, which ERP and MRP could not produce because such data usually was reported on a daily or even monthly basis (Chen & Voigt, 2020). MES is an overall system for controlling and monitoring production processes and resides between the ERP layer and the actual production. The system delivers information from order launch to finished goods and is enabled to optimize production activities. With the continuous collection of data from connected devices and sensors, the MES makes it possible to respond to real data and activities as they occur. Being able to respond to changing conditions, coupled with a focus on reducing non-value-added activities, drives efficiency in the manufacturing process and improves production efficiency (Manufacturing Enterprise Solutions Association [MESA], 1997a; Jaskó et al., 2020). The MES is the bidirectional link between enterprise planning and the shop floor. It creates operations plans from the ERP based on data from the processes, materials, and individuals instantaneously. An MES should be organized and easy to use with the purpose to assist human decision and prevent human error to achieve an error-proof shop floor (Shojaeinasab et al., 2022). The wide range of functionalities in an MES solution can leverage investments made in plants, capital, material, and human resources (MESA, 1997a).

Shojaeinasab et al. (2022) point out that an MES is a key enabler of I4.0 as it contains the fundamental features and concepts of I4.0 and that it can fully integrate the physical production system into a digital one, called DT. Kritzinger et al. (2018) introduce a classification of a DT through a categorical review of existing literature in this field. The DT is in its essence a complete integration between an existing physical object and a digital object with bi-directional communication and actions flowing between the entities. Therefore, a change in the digital object will trigger a change in the state of the physical object, and vice versa. Shojaeinasab et al. (2022) clarify that an MES in regard to functionality and how well it supports I4.0 (automation and intelligence) can attain five different intelligence levels, see Figure 2. The five intelligence levels are divided into: Digitalization (computerization and connectivity), Visibility, Transparency, Prediction, and Adaptability (Shojaeinasab et al., 2022).

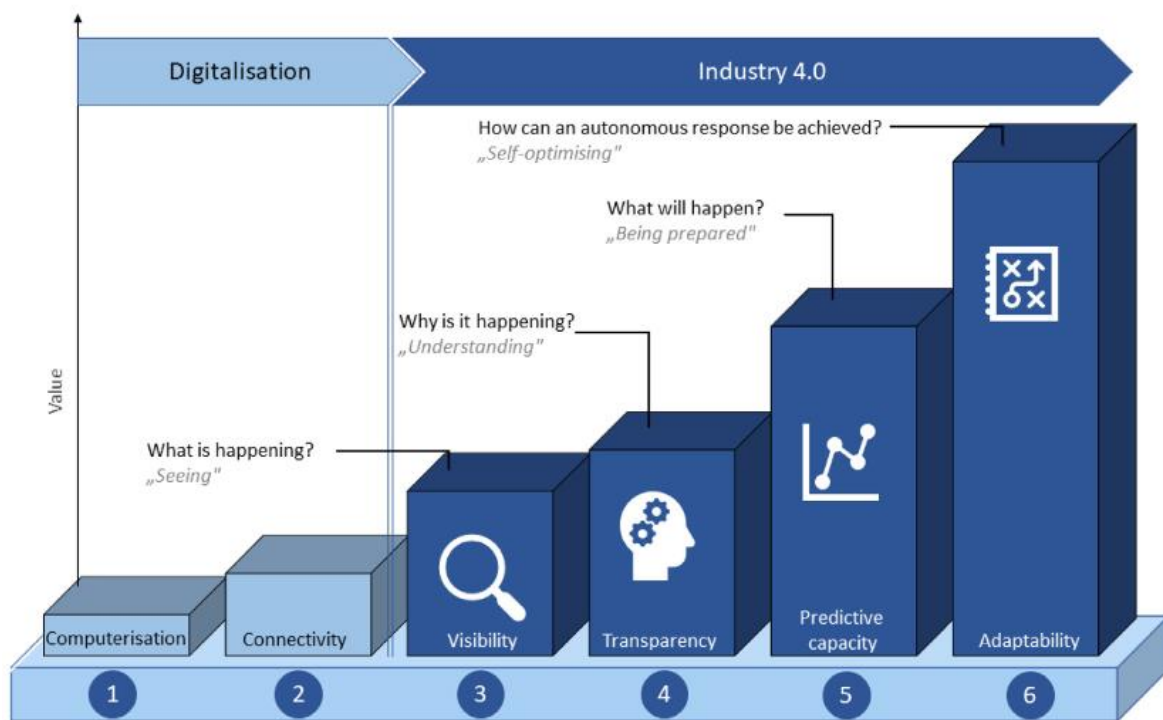


Figure 2: Depicts the different intelligence levels an MES can achieve in accordance to support I4.0 (Jaskó et al., 2020, p. 3)

Digitalization (computerization and connectivity): includes controlling and improving the production process using IT and ensuring fully integrated communication between the connected information sources, in real-time. Digitalization is a prerequisite for companies to be able to develop in accordance with I4.0. The usage of sensors in the production environment that collects and organizes data can contribute to digitalization (Shojaeinasab et al., 2022)

Visibility: The MES should embrace higher levels of visibility in production. This functionality will include monitoring the production, tracking specific details of an order, and other valuable insights that can be gained from the data gathered by different sensors (proximity, temperature, and pressure sensors). The tracking of specific details at any stage of the production process can be achieved by using Barcodes and RFID tags with read and write capabilities, which in turn ensures visibility (Shojaeinasab et al., 2022).

Transparency: MESs can give a more perceptive understanding of the production processes by utilizing smart sensors and intelligent software. The MES can organize the data into a manageable format and can utilize AI to gain valuable insights from the historical, and real-time data (Shojaeinasab et al., 2022).

Predictive Capacity: At this level, an MES can assist decision-making by leveraging predictions on what the state in the future would be. and how does this state transition take place? The ability to predict when and where maintenance of machines, equipment, and robots should be addressed within the predictive level. This maintenance is a critical factor in the manufacturing industry due it has an impact directly on the human and production (for example time or service) (Shojaeinasab et al., 2022).

Adaptability: In order for an MES to achieve this intelligence level the system has to utilize the collected real-time data to optimize itself in response to different situations. The decisions that need to be taken to adapt can be different in terms of complexity. Hence, a truly adaptable MES should assist multi-objective real-time decision-making as the actions often have to be taken immediately to ensure adaptiveness (Shojaeinasab et al., 2022).

3.2.2 MES impact on operational and financial performance

Regardless of the company's size, industry, complexity, etc., all can take advantage of the benefits of using an MES, although the benefits may be different regarding the differences in priorities and objectives (MESA, 1997b). Traditional manufacturing companies are hierarchical and divided into different functions in the organization. The flow of information or material between one function or hierarchical level to another involves a transition called an interface, which involves a break in communication that is costly, and time-consuming with increased error probability which affects the quality negatively. Every interface generates documentation that companies spend money on, only for producing and managing paper. Printing costs alone for larger companies are esteemed to be around 5% of their sales volume (Kletti, 2007). Implementing an MES can contribute to less paperwork which thus can improve the firm's financial performance (MESA, 1997b). Reducing the paperwork in the production can lead to operational benefits as it lowers the risk for quality errors (Kletti, 2007). Nanggong & Rahmatia (2019) found that becoming paperless minimizes the cost and is more sustainable by using fewer natural resources compared to paperwork. MES can provide the ability to make the working instructions digital which enables them to inspect and monitor the production data in real-time. The MES does not only replace the need for paperwork but also the manual labor associated with data acquisition and digitization of information which minimizes the data entry time and thus increases personnel productivity. This can in turn reduce both the liability and operating costs whilst improving customer service and return on human and other assets (MESA, 1997a; Kletti, 2015, referred to in Chen & Voigt, 2020; MESA, 1997b). Additional areas that will benefit from the implementation of MES are reduced lead times and increased flexibility since MES will bring transparency and a greater synchronization of the production process. The operational improvements made by implementing an MES will in turn affect their financial performance beneficially. If the products can be produced at a lower cost and with better quality, it should result in increased market share and thus competitiveness. It is also concluded that the benefits to be expected from implementing an MES will increase over time with further investments made in the solution, see Table 2 and Table 3 for a summary of the expected outcomes from implementing an MES (MESA 1997a).

Table 2: Summary of expected operational outcomes from implementing an MES according to the existing literature.

Expected operational outcomes	Source/Reference
Personnel productivity	MESA, 1997a; Kletti, 2015 (referred to in Chen & Voigt, 2020);
Reduced Lead time	MESA, 1997a; MESA, 1997b; Kletti, 2015 (referred to in Chen & Voigt, 2020);
Flexibility	MESA, 1997a;
Data entry time	MESA, 1997b;
Quality	MESA, 1997b; Kletti, 2015 (referred to in Chen & Voigt, 2020); Kletti, 2007
Eliminates paperwork	MESA 1997b;

Table 3: Summary of expected financial outcomes from implementing an MES according to the existing literature.

Expected financial outcomes	Source/Reference
Market share	MESA, 1997a;
Cost reduction	MESA, 1997a; Kletti, 2007; Nanggong & Rahmatia, 2019
Competitiveness	MESA, 1997a;

According to Shojaeinasab et al. (2022), MES is a powerful technology, yet there are some challenges and obstacles that need to be addressed during its adoption. Firstly, the capital investments required to adopt and maintain an MES can be costly and make it difficult for small and medium enterprises (SME) to afford an adoption. Secondly, the hindrance of adoption is related to the lack of capabilities and qualifications of the workforce because a sophisticated MES needs to fit the production environment and has staff that can manage it. Lastly, the resistance to change is an impediment to adoption that is fueled by fear of losing jobs to automation (Shojaeinasab et al., 2022). Chhor et al. (2022) also conclude that implementing an MES can be costly in financial terms and require technical skills from the IT staff.

3.3 Low-code and No-code (LCNC)

3.3.1 The background of LCNC

Low-code is a growing approach that lowers the skills required in software development by eliminating most of the coding needed (Pinho et al., 2023). Low-code platforms can manage the overall network of a collaborative manufacturing and logistics environment. This collaborative network enables communication and interaction between people, applications, and Internet of Things (IoT) devices in interconnected settings. This promotes resilient digital transformation, which is important for businesses to remain competitive as the digital world is constantly evolving. To stay ahead of the competition, enterprises need to quickly develop new digital solutions, and low-code development platforms can be a possible solution to this challenge (Sanchis et al., 2020; NIC, n.d.). The backside with low code is that it still requires the enterprise to have technical skills to write lines of code, even if its fewer lines compared to traditional approaches. But there is another emerging variant of low-code called no-code which touts itself as making it possible to eliminate all coding. No-code lacks a formal definition but means that end-users can develop the software through visual programming and drag-and-drop features to eliminate the need to write codes (Pinho, et al., 2023).

2.3.2 LCNC's impact on operational and financial performance

Many experts highlight the benefits of deploying LCNC applications for a multitude of reasons. By utilizing LCNC features such as drag-and-drop and visual programming with different configurable parameters to meet the needs and requirements of the user. The LCNC capabilities allow developers to set aside more time for value creation, instead of writing and reproducing standardized codes. This promotes innovation as it enables a focus on creating unique features with the ability to demonstrate the ideas quickly in practice via intuitive features (Turner, 2023; Pinho et al., 2023; NIC, 2023). For digitalized processes, a no-code platform can facilitate quick and agile adoption of modifications made in the processes (Chhor et al., 2022). It's also pointed out that LCNC is easier to understand compared to traditional coding, which makes debugging and fixes easier to maintain when problems arise (NIC, 2023). Additionally, software and applications built using LCNC software are not limited to developers. Technical business stakeholders can also leverage these tools to build and scale enterprise-grade applications without requiring large engineering teams or infrastructure (NIC, 2023). The testing and validation activities that were previously handled by professional developers can now be executed by other personnel with less technical skills, which increases efficiency and lowers the skill barrier in software development (Turner, 2023; Pinho et al., 2023; NIC, 2023). Pinho et al. (2023) identified the most common benefit of LCNC was that the technical skills were lowered due to a higher grade of usability. The importance of lowering the skill barrier in software development is evident due to the labor shortage of a technically skilled workforce that is expected to arrive soon. The US Bureau of Labor Statistics (BLS) estimates that the growth in software developer jobs will increase by 22% in a 10-year period, whilst at the same time the American Council on Education (ACE) reported that graduates from computer and information science declined by 43% in pandemic-era enrollments. The increased difficulty in hiring technically qualified personnel from a tighter IT labor market could result in lost productivity and reduced innovation (Breux & Moritz, 2021).

Some experts pointed out the benefits of cost reduction, faster development of products, and the ensuing process transparency (Bhattacharyya & Kumar, 2021; Pinho et al., 2023; NIC, 2023). Medium and Small-Scale Enterprises (MSMEs) could leverage the cost-effective and easy-to-maintain LCNC application development to help level the playing field against large corporations (Bhattacharyya & Kumar, 2021). An example of a successful implementation of LCNC is the company Murata Power System (MPS). In November 2019 they announced that they wanted to adopt a modern approach by employing a “low-code” development capability to create IT applications for internal use. This approach is characterized by its ability to replace the intricate and time-consuming manual processes executed by skilled IT development personnel with a more straightforward methodology that employs user-friendly “grab-and-drop” routines. This allowed non-technical staff to create software that met their specific needs, resulting in significantly reduced development timescales. The outcome was software systems that concentrated on automating vital business processes. In MPS’s first project, they achieved a 50 percent time-of-effort saving in developing time. This example is one of several that proves that you can achieve a high return on investment in low-code technology (Farish, 2020). See Table 4 for a full summary of the expected operational outcomes and Table 5 for the expected financial outcomes of LCNC that were identified in the existing literature.

Table 4: Summary of expected operational outcomes from using a no-code platform for software, according to the existing literature.

Expected operative outcomes	Source/Reference
Reduced development time	Farish, 2020; NIC, 2023; Sanchis, 2020; Pinho et al., 2023.
Increased efficiency	NIC, 2023.; Pinho et al., 2023.
Agility	Chhor et al., 2022

Table 5: Summary of expected financial outcomes from using a no-code platform for software, according to the existing literature.

Expected financial outcomes	Source/Reference
Cost reduction	Bhattacharyya & Kumar, 2021; NIC, 2023; Turner, 2023; Pinho et al., 2023.
High return on investment	Farish, 2020

4. Findings

4.1 About MTEK

MTEK was founded in 2002 as a consulting company in manufacturing excellence and digitization, based on experience from high-tech manufacturing. MTEK has its headquarters in Alfta and has approximately 60 employees in Sweden, Germany, and the USA. MTEK is currently expanding its team and geographic focus across both Europe and North America. They are specialized in providing a software platform that allows a higher degree of flexibility, control, and speed for manufacturing companies. Their legacy is manufacturing, and they take pride in truly understanding their customer's everyday challenges. MTEK supports the people who make things, with the mission to help them “*Make Things Better*”. They firmly believe that their approach to digitalization will help companies improve their operations and supply better products to their customers, and for the planet (MTEK, n.d.).

4.2 About MBrain

MBrain is a no-code manufacturing execution platform that interlinks manufacturing processes in an end-to-end flow and was developed by MTEK. MBrain had its market launch in the fall of 2020. MBrain is built to support people and processes in manufacturing by leveraging data. MBrain also sustains paperless manufacturing by utilizing digital working instructions, barcode generation and scanning, and comments and input fields. Digital working instructions are the foundation for becoming paperless. Making working instructions digital gives a higher level of flexibility and control and enables quick changes that get saved across the entire production facility. Barcode generation and scanning that is utilized in MBrain means that information about products and components can be securely traced throughout the entire production process. Comments and input fields about the component or product are passed from cell to cell digitally to ensure sustainable and efficient tracking compared to handling the paperwork. The end-to-end digital traceability eliminates the need for paper stacks to accompany the product along the process, which reduces both the carbon footprint and the number of errors (MTEK, n.d.).

MBrain’s production planning and scheduling tools allow manufacturers to plan the production across the connected manufacturing footprint. The planning and scheduling tools are built upon no-code with drag-and-drop functions. When planning the production MBrain will ensure that the correct digital working instructions and other parameters follow the order throughout the production process. The digital working instructions and other parameters for each process step are configured with drag-and-drop in the “Process Builder”. The Process Builder enables quality control through validation points at each process step to enable quality assurance. Validations of quality can be done either manually by the operator or automatically by MBrain via machine data, sensors, or tools. Another parameter that can be configured is takt time requirements. The configured digital working instructions are transformed into the “Process Viewer”, which displays all the necessary information and instructions at the right time and places to the operator in the production process (see figure 3). This aids the operator in successfully executing the operation for the order. If quality problems arise during production, andon signals can be sent to the designated recipient over Microsoft Teams. The Andon signal can be triggered either automatically if e.g., the takt time is exceeded or manually by the operator (MTEK, n.d.)

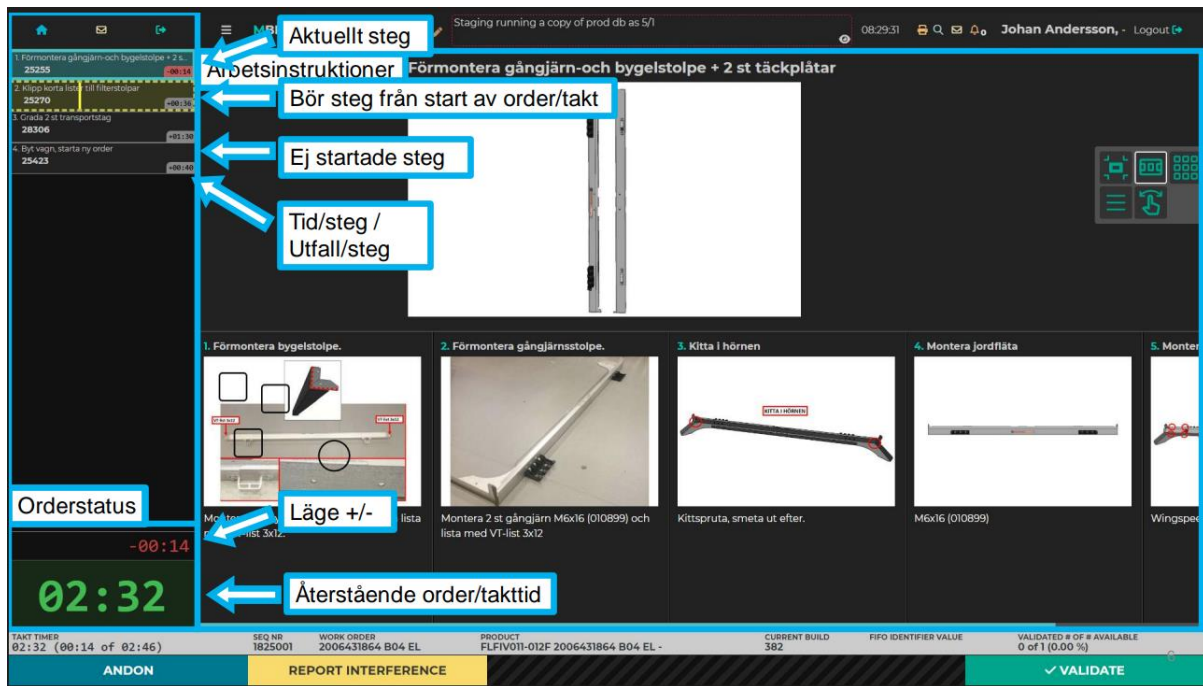


Figure 3: The Process Viewer in MBrain. Source: MTEK (n.d.)

MBrain provides the ability for Personalized Digital dashboards that provide a live status of the real-time data on the shop floor. The dashboards can display information such as the status of each cell in the line, and the stock levels in the buffers that are feeding the line, as shown in Figure 4. The Digital Dashboards are configurable and adjustments can be made with drag-and-drop functionalities. The dashboards can be configured to include predictive capacity. For example, will the buffers in the dashboards indicate a color lining if there is a risk of running out of material if no actions are taken. MBrain is able to collect and store all collected data from virtually any machine, sensor, system, tool, or other item that has the ability to transfer data. The detailed logging of data in MBrain gives traceability to understand who has done what, where it happened, at what time, and with what disturbances or interferences. The collected data can be transformed into MBrains data collection tool to further contextualize and leverage the data throughout the system to achieve a data-driven continuous improvement process. All the features and the area of use in MBrain are summarized in Table 6.

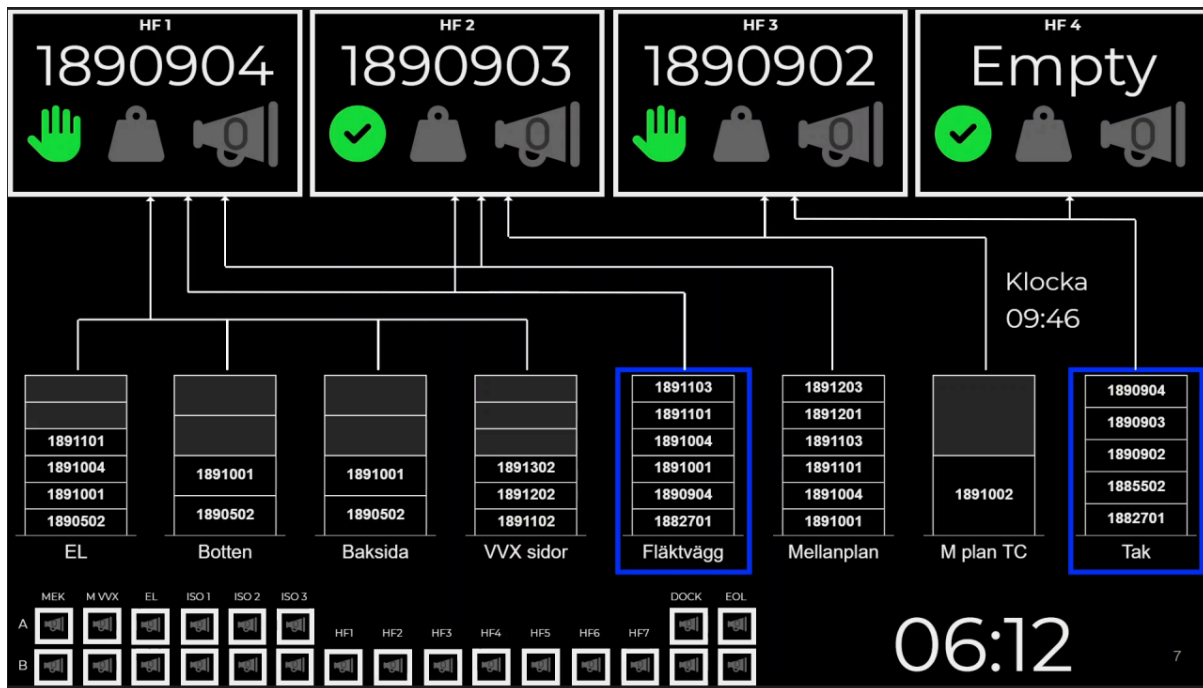


Figure 4: Personalized Digital Dashboards in MBrain. Source: MTEK (n.d.)

Table 6: Summary of MBrain’s features and the area of use.

Feature	Area of Use
Planning and Scheduling tools	Use drag-and-drop function to plan the production.
Process Builder	Create process steps and digital work instructions that can be reconfigured with ease. Validation points can be set for quality assurance.
Process Viewer	Visualizes the correct instructions and information, to the correct order, in the right time with validation points for the operator after conformance to quality.
Andon	Ability to send error signals manually or automatically via MS Teams to signal for help.
Personalized Digital Dashboards	An overview on live status of the shopfloor and real-time traceability, with predictive capacity.
Data Collection	Ability to contextualize collected real-time data, as well as historical data through report making.

4.3 Case Company 1

Company 1 is a manufacturer of ventilation systems that implemented MBrain in January 2023. They produce their products in modules that serve different functions that are then assembled into complete ventilation systems for indoor climates. Their modular design results in 80 million billion different combinations of complete systems and each year they produce approximately 9000 ventilation systems, in the words of Respondent 1. Company 1 has 300+ employees with annual revenue exceeding 1,7 billion SEK.

How does Company 1 utilize MBrain and what are the outcomes?

Respondent 1 explains that MBrain is primarily used to make digital working instructions that are configured according to the specification of the customer order and that each step of the process is presented at the correct time and place to the operators. Besides displaying digital working instructions, MBrain tracks and monitors all time and labor associated with the order to enable the ability to make reports and to improve the production process. Respondent 2 points out that MBrain in production is used as a support to ensure that the products are assembled correctly, even by operators with experience, and to validate that the specifications are met at each cell. MBrain displays the instructions that are linked to each activity and visually shows the time that each activity should take, as well as the elapsed time. The takt time that is used in their production as of now is 7 minutes and 37 seconds, which means that after each takt there will be one complete unit produced. Operators with less experience use MBrain to a wider extent and read the instructions as well as view the picture/s, in more detail compared to operators with more experience.

They also use MBrain to provide Digital Dashboards in the facility for the operators with the andon function to signal when problems arise eg., takt time is exceeded, potential material shortage etcetera. Respondent 1 explains that MBrain predicts potential material shortages by displaying statuses of different colors in the dashboards to the operators, as well as andon signals for all personnel on the line to observe. Respondent 2 highlights the usage of dashboards to ensure an overview of the status of the other cells in the production line. The dashboards are configurable, which Respondent 1 highlights as an important feature as the company wants to be able to make fast adjustments in their dashboard if any operator has an input of what they want to see. Respondent 2 says they use them to display what order that is being produced, if there are any problems with any station, and if some of the stations have a highly complex order that might need more takt time than usual. These complex orders might result in a bottleneck, but the dashboards have enabled their management and production personnel to be more proactive in their efforts whilst dealing with these orders.

Prior to implementing MBrain, Company 1 used a different MES solution that had digital working instructions, but not the other features provided by MBrain (andon, takt, dashboard, and control of the time at each step of the process). They previously had a board in the ceiling of the production facility that showed general information such as takt and stop time (time with no production), the number of products, and a clock, according to Respondent 2. In the previously used MES solution, the operator had to manually transfer the order in the production flow which took time. MBrain automatically transfers the order to the next station when each step is completed which has resulted in time savings, as mentioned by Respondent 1. The takt time that was used prior to having digital working instructions was about 40 minutes per station as stated by Respondent 2.

The motivations behind the decision to adopt MBrain in the opinion by Respondent 1 was primarily they did not want to have different solutions for digital instructions, andon signaling, and dashboards. Their previous supplier of MES was not flexible in adapting their solution to their needs whilst at the same time raising their prices. Instead, they sought a software provider that had multiple functionalities that fit their environment. With MBrain they received all the functionalities they sought, and at a lower price point based on the input from Respondent 1.

There are many differences in how Company 1 works after implementing MBrain. Respondent 2 explains that without digital working instructions, going from 40 minutes to less than 8 minutes (7m 37s) would not have been possible. There has also been an improvement in getting the right information, at the right time, and in learning the tasks that are necessary for production, “it is now easier to learn”. The amount of different product variants makes learning a necessity because some products are rarely manufactured, which is why digital working instructions can be of support, as stated by Respondent 2. Respondent 1 concludes that MBrain is a necessity to be able to manufacture the vast range of different combinations and at the speed they do. They would be able to manage their flexible manufacturing without MBrain but would incur significantly higher operating and training/onboarding costs and would not be able to manufacture at the same speed and performance. Respondent 2 said, “*Without MBrain, every employee would need to have 14 years of experience to handle the complexity while achieving our takt time*”. Respondent 1 clarifies that the digital working instructions in the Process Viewer facilitate quicker learning and make it easier to transfer staff between different stations and tasks.

Respondent 2 highlights the beneficial difference in how they now can keep track of the time it should take to complete each task in each station, which is a new feature. The time starts to count when the order is activated and shows the time each individual task should take. As reported by Respondent 2, there were concerns about increased stress in seeing information about the time at every step. However, the results are the opposite, the operators feel calmer in seeing their progress and receive more control over how they manage their work. This has according to Respondent 2 resulted in a more proactive way of working and gives the ability to signal for help earlier than before. By using MBrain the personnel have better conditions to interpret the current situation in the same way which is beneficial in the opinion by Respondent 1.

Furthermore, Respondent 2 explains that the personnel have gotten more connected and collaborative as a result of seeing the status of other cells in the production, via the configurable Digital Dashboards placed in the facility through TV screens. The dashboards enable a quick representation of the status where they can see if, and where (what cell/location) help is needed and if the buffers are full or are in dire need of replenishment. Before MBrain the operators had to walk across the facility to check the physical buffers and did not have the ability to acknowledge when other stations had problems, now they can look at the screen to get an indication of what, and where work needs to be done. Respondent 1 explains that the overview the dashboard brings can assist the operators by displaying abstract information in one place, instead of having different systems to navigate. The dashboards further enforce the possibility of the operators interpreting the situation in the same way. As Respondent 1 points out, *“The visualization has contributed to clearer and crystallized information”*.

Respondent 1 explains that they currently have MBrain fully implemented in half of their production lines after 4 months of using MBrain. During the implementation of MBrain, management prioritized the introduction at a small scale with a focus on involving and being transparent towards the operators regarding the project, according to Respondent 1. After the small-scale test, they implemented it fully in production for three days so that they could compare MBrain to their prior MES solution. The feedback that was brought forth by the operators was used to improve the implementation efforts, and MES solution to fit to their needs. Respondent 2 says that the implementation experience has been satisfactory, both in how the system works and how the implementation of the system was arranged. *“I think on our line, Line B, about 90% of the personnel is super satisfied with the overall experience with MBrain”*, said Respondent 2. Personnel from MTEK (the company that develops MBrain) was present during the implementation to assist them and collect feedback to further improve their MES solution, as stated by both respondents.

Respondent 1 clarifies that their company strives to achieve high-quality products that get delivered on time and manufactured at the lowest cost. Even though Company 1 only has used MBrain for three months, and in half of their production lines, they have attained some beneficial outcomes. Respondent 1 says there are clear tendencies of better compliance with the intended way of working, which means that the operators are better at following the instructions. Respondent 1 further points out that the visualization of the production flow that MBrain brings has contributed to better measurement attainment. Since they started to use MBrain, Respondent 1 says that their productivity has increased. Respondent 1 highlights the benefits of visualizing information for the operators and highlighting the most important parts for them which will make it harder to interpret the same situation differently. Respondent 1 says *“It is almost like the difference between a picture and a 3D model, in a 3D model you can focus on the most important parts and remove the clutter.”*.

Respondent 1 believes that the visualization brought by having configurable working instructions can make it easier for newly recruited personnel to distinguish what parts of the task that are particularly important. Respondent 1 concludes the interview by saying that without a flexible solution such as MBrain, they would not be able to have such a flexible manufacturing process and have so many different variants. The costs of having highly flexible manufacturing have been lowered to a reasonable cost.

4.4 Case Company 2

Company 2 is an energy storage developer that produces energy storage solutions worldwide. They were one of the first customers to implement MBrain and the year was 2021. According to the Company's website, it was founded in 2015 and has over 600 employees and has installed over 350 000 batteries.

How does Company 2 utilize MBrain and what are the outcomes?

Company 2 uses MBrain to make digital work instructions, Digital Dashboards, create reports in data collections and manage, control, and trace the test-and production flows. Respondent 3 explains that their digital work instructions are shown in the Process Viewer and are configured in the Process Builder, to include both gifs and images so everyone can understand the instructions regardless of their native language. Each digital work instruction is also connected to one station and product and the operator validates when their job is done. The activity to transfer the order to the next station in the production flow is handled automatically by MBrain. Their dashboard is configured differently depending on who the user is. The operators are keener to see the status of the production while test engineers use the dashboards to set up various test cases that they monitor throughout the day to see if any problems arise. Respondent 3, who is the site manager, says that he uses data collection to create monthly reports. The company uses traceability in MBrain to track and monitor components in production. Respondent 3 gives us an example of how they can utilize this data if problems occur with any components. Instead of recalling about 4000 units they can trace and see which units that were made in the same batch and recall only the affected units.

Before Company 2 implemented MBrain they only had one factory, which was placed in Mexico. Respondent 3 said that instead of using the digital work instructions in the Process Builder they had all the work instructions on paper. They didn't have any dashboards for visualization either. For traceability and production overview, they used their self-created MES solution and for test production, they had a separate system. Their previous system was complex and there was only one person at the company who had the right technical skills and could manage the system. Respondent 3 explains that before they implemented MBrain they didn't have the opportunity to create reports via data collection as they do today. Instead, they imported the data into Excel to make reports there.

Respondent 3 explains that one of the biggest differences in the way of working when implementing MBrain compared to the previous business system is that more people can manage the system now. According to Respondent 3 it takes only a few hours to learn how to handle the system. It also points out that it is very user-friendly to create production flows in the Process Builder and that they use drag-and-drop as much as possible. This facilitates their daily work as they create new prototypes almost every week which requires new production flows set up frequently. Without MBrain, Respondent 3 are sure that it would be too time-consuming to add new flows all the time in another system, so without MBrain they would probably have to run these flows outside the system. Respondent 3 also adds that the problem with running flows outside the MES system is that important data might not get collected or end up in someone's folder that could possibly get lost or be hard to find. Respondent 3 says *"With MBrain we can have all data information collected and saved in one place"*.

Another big difference with using MBrain is that the company can control and make adjustments in the production in Mexico, Vietnam, and South Africa at a distance from the site in Sweden. In opinion by Respondent 3 s, it had not been possible with the previous system. It is also told that when the factory in Vietnam was to be set up, they could do it from Sweden, thanks to MBrain. Which benefited them because the setup was carried out during the Covid-19 pandemic.

On the question of the main reason why they implemented MBrain, Respondent 3 answered that the main reason was that they planned to expand their business with two new factories abroad (Vietnam and South Africa). They realized in the planning stage that their previous system was too complex and when the company started to go worldwide it was not manageable that only one person could manage the system. Respondent 3 continued the backstory by explaining that they started to search for a software provider and found MTEK. They chose MTEK and MBrain for several reasons but partly because they are a Swedish and newly started company that offered a flexible system. Respondent 3 points out that they together with MTEK have developed MBrain in accordance whit their desires and needs. Respondent 3 highlights that MBrain is adaptable to the customers rather than that the customer has to adapt to the system, compared to other software providers.

On the question of how long it took to implement MBrain and how the experience was, Respondent 3 answered that it took the longest time to implement MBrain in their factory in Mexico. The reason for that, according to Respondent 3, is that they already had a MES that they had to replace and therefore encountered some resistance from the operators used to the previous MES solution. But it took around 1-1.5 weeks to implement MBrain and set up all the production flows in Mexico. In the factories in Vietnam and South Africa, it went a little bit faster, and both were implemented within one week. Respondent 3 believes that the rapid implementation of MBrain is due to its flexibility and that more than one person could help to set up the production flows.

In the interview with Company 2, Respondent 3 says that they don't have a measurement of how MBrain has affected them operationally or financially. But it is said that if they need to make any adjustments in the production due to a quality problem, they can do these changes way faster than before. They can do adjustments in the site in Sweden, and when the result of the changes is improved, they can implement the same adjustments in their other factories. Respondent 3 also clarifies that they can retrieve data faster and easier with MBrain than before. If there are any problems it is easier to see what has happened, when was the unit built, who built it, and how many units were built during that time. Before MBrain it could take days to get that information and now they can have it in a few hours. Due to the increased user-friendliness, Respondent 3 explains that they don't need to have IT support to do technical adjustments in the system. Company 2's IT-support has nothing to do with MBrain. Instead, they focus on their main tasks such as setting up servers, etc. According to Respondent 3, traditional MES solutions require assistance from the IT department when adjustments in the system must be made, which consumes both time and costs.

5. Analysis & Discussion

There are several beneficial outcomes that can be expected, regardless of the characteristics of the company implementing an MES, as it focuses on, and improves the core value-adding processes. The implementation of an MES can contribute to a paperless factory (MESA, 1997a; MESA, 1997b). Both companies use the Process Builder in MBrain to create and edit digital working instructions that are displayed to the operators in the Process Viewer. As the information gets digitized it would induce less paper consumption and manual labor (Kletti, 2015 referred to in Chen & Voigt, 2020). As stated by MTEK (n.d.) digital working instructions ensure the support of paperless manufacturing which will reduce the carbon footprint. Company 2 had all their working instructions on paper prior to adopting MBrain whilst Company 1 already had digital working instructions in place. Kletti (2007) highlights the financial savings that can be achieved in eliminating the use of paper which Nanggon & Rahmitia (2019) supports as being paperless minimizes the cost and use of natural resources. Reducing the amount of information being held on paperwork has shown to remove manual labor and would also result in less natural resources consumed for both companies, and thus support sustainable manufacturing. It would therefore be a fact that manufacturing companies will benefit financially, operationally, and sustainably by implementing a no-code MES.

The elimination of paperwork brings operational benefits in lowering the error probability associated with managing paper which positively affects the quality (Kletti, 2007; Kletti, 2015 referred to in Chen & Voigt, 2020). As Company 1 and 2, eliminates the necessity of paperwork with the utilization of MBrain's features, the error probability should thus be minimized which should result in increased quality. Furthermore, should an MES enable the response to real-time data by constantly gathering data from the production process (MESA 1997a; Jaskó et al., 2020), which in turn according to Kletti (2015, referred to in Chen & Voigt, 2020) can further increase the quality. MBrain sustains an end-to-end traceability by utilizing digital working instructions with the usage of barcodes to enable tracking of products and components in the production (MTEK n.d). Company 2 utilizes MBrain's real-time data gathering throughout the production process to support its quality efforts. MBrain provides the ability to track and automatically monitor the production which helps Company 2 if any problems occur with a product or component. When products have quality issues, they can trace what happened, when the unit was built, who built it, and how many units were built at that time to ensure transparency in their processes. Making reports to get this knowledge previously could take days to collect and analyze, but in MBrain Company 2 can do it in a few hours owing to the intuitiveness gained from having the MES built on no-code elements. There is no evidence from the findings that Company 1 exploits the traceability to improve the quality. However, their compliance with the intended way of working has increased after implementing a no-code MES, which should result in increased quality as well, as the products are assembled in the correct way more often than before. Further, has MBrain's feature "data collection" been beneficial as it has saved data entry time, which supports MESA (1997b) findings in the commercial value of MES. Prior to MBrain, Company 2 had to manually import the data into Excel to make reports, which is now automated with all data at the same place in MBrain. Having all data in the same place and being able to contextualize the data to draw insights, indicates that MBrain achieves transparency, which is the fourth intelligence level as explained by Shojaeinasab et al. (2022). The operational benefit of having the ability to trace the quality issue has resulted in fewer recalled units for Company 2. This operational benefit of being able to trace the problem to its source and thus recall only the affected units, instead of the whole batch, should result in lower costs associated with quality issues and thus achieve beneficial

financial outcomes. It can from the findings be concluded that a no-code MES ensures transparency and will bring operational benefits that increases the quality which in turn will improve the financial outcomes.

Furthermore, can an MES contribute to higher personnel productivity by minimizing and facilitating manual labor and paperwork. When paperwork is minimized the operational and financial performance can be improved by reducing the time needed and error risk associated, improvements will be further gained by having improvement efforts that are data-driven. (Kletti, 2005; MESA, 1997a; MESA, 1997b). After Company 1 implemented MBrain they were able to reduce their takt time from 40 minutes to less than 8 minutes in their production, which accounts for an 80% improvement in takt time. One reason they were able to reduce the takt time is the digital work instructions in MBrain. Digital work instructions are a necessity for Company 1 due to the vast number of different product variants they have in their production (80 million billion combinations). Company 1 would be able to manage their flexible manufacturing without MBrain but would incur significantly higher operating and onboarding costs and would not be able to manufacture at the same speed and performance. They previously had digital instructions but with the no-code MES they have attained a higher compliance of the intended way of working. Company 2 digital working instructions are configured in the Process Builder, to include both gifs and images so everyone can understand the instructions regardless of their native language. With MBrain, both companies have automated the manual labor of transferring the order to the next station in the production flow, compared to their previous solution. Furthermore, Company 1 solution only showed the total takt time for the complete process, while MBrain shows the status in detail for every step of the process. The operators in Company 1 thought seeing the takt time in detail would induce stress, but highlights that the results are the complete opposite. The utilization of MBrain's features, such as providing digital working instructions and automatically integrating them into the production process, leads to more productive personnel. Consequently, this improved productivity results in a reduction of takt time for Company 1, yielding significant operational benefits. With MBrain's support, as a no-code MES, operators can focus on more crucial tasks and allocate their efforts where they are most required, rather than merely transferring orders to the next station.

MES is an overall system that oversees and manages all stages of production processes. It creates valuable insights from the data gathered throughout the production process and facilitates the optimization of the production flow. An MES should assist humans by embracing higher levels of visibility in production through monitoring and tracking the production processes to avoid any errors (Shojaeinasab et al., 2022). The personalized dashboards in MBrain provide an overview (visualization) of the status of the production in real-time (MTEK, n.d.). Company 1's implementation of configurable Digital Dashboards in the no-code MES has resulted in the operators sharing a unified visual representation of the production status. This shared understanding is crucial, as the Digital Dashboards exhibit critical statuses for production cells and stations. These dashboards empower and assist the operators to adapt to various scenarios effectively via visualization, which Shojaeinasab et al. (2022) highlight is the third intelligence level (Visibility) of an MES. Company 1 further leverage MBrain's Digital Dashboards with a predictive capability, which utilizes different colors to indicate when the buffers feeding their production line are nearing depletion, or when the takt time in any station is exceeded. This indication helps the company adopting a no-code MES to be more proactive in order to avoid potential issues before they occur that may be caused by either replenishment issues from the buffers or when problems at any station occur. This predictive feature indicates the fifth intelligence level (Predictive Capacity) of an MES, as mentioned by Shojaeinasab et

al. (2022) claims. Company 2 also uses Digital Dashboards, but the only available respondent from the company has no direct connection to their physical production, he was unable to elaborate on how they use them. But since the Digital Dashboards according to MTEK (n.d) are intended to provide status in real-time, the authors assume that Company 2 has beneficial outcomes with using Digital Dashboards in MBrain as well. It can be concluded that a manufacturing company that adopts a no-code MES will bring operational benefits in increased personnel productivity as the system ensures visibility and has predictive capacities.

LCNC development lowers the skills required to manage applications by replacing manual coding with drag-and-drop and visual features which will promote competitiveness and free time to focus on value creation (Pinho et al., 2023; Sanchis et al., 2020; Turner, 2023). Companies 1 & 2 highlight the beneficial outcomes from the no-code features when configuring MBrains features and that adjustments can be made at ease, and by multiple personnel. The usability of no-code MES, which enables more personnel to manage the system could also be a possible solution to mitigating the effects of the upcoming labor shortage, as stressed by Breaux & Mortiz (2021). Company 2 points out that MBrain in comparison to other MES solutions is more user-friendly and does not require programming knowledge which enables personnel with less technical skills to operate the system, which supports Turner's (2023) claims that LCNC lowers the technical skills required. This has enabled Company 2's IT-department to not be involved in managing MBrain, and to instead focus on their key task for the company which has resulted in both time and cost savings. This finding indicates that the intuitiveness gained from the no-code elements in MBrain, does not incur the need for high capital investments and technical skills that traditional MESs, which do not have no-code features, as mentioned by Chhor et al. (2022) and Shojaeinasab et al. (2022).

The operational improvements made by implementing an MES will in turn affect their financial performance beneficially (MESA, 1997a). If the products can be produced at a lower cost and with better quality, it should result in competitiveness and thus increased market share. Guo & Xu (2021) pointed out that the utilization of digital technologies has a positive and lasting impact on the operational performance but the financial performance lags which means that profits are expected to be realized after two to four years. As both companies have only been using MBrain for a couple of months it is too soon to be able to pinpoint how much their finances have been affected. Representatives from both companies indicate that MBrain is a cost-effective and easy-to-maintain MES solution with many beneficial features that support them in their operations. MESA (1997a) claims that the benefits to be expected from implementing an MES will increase over time with further investments made in the solution. Adopting a no-code MES could be a possible solution for SMEs to level the playing field against large corporations, which supports Bhattacharya & Kumar's (2021)'s finding that LCNC are cheaper and easier to manage. This is an important finding as Shojaeinasab et al. (2022) point out that SMEs have difficulties in affording the adoption of MES. It can thus be concluded that a no-code MES will bring beneficial financial outcomes, that will increase over time and that it makes a more cost-effective and easy-to-maintain alternative to traditional MESs, which do not have no-code elements.

Based on to the study conducted by Chhor et al. (2022), it was concluded that the utilization of no-code elements enables agile and efficient adaptations for digitalized processes. The ability to make efficient adaptations for both case companies participating in this study are the motivations behind adopting a no-code MES. One noteworthy distinction when implementing MBrain is the ability of Case Company 2 to remotely control and make necessary adjustments in their geographically dispersed manufacturing facilities, from their site located in Sweden. Company 2 affirmed such capabilities were not feasible with their previous system which was complex and could only be managed by one person. Furthermore, it is mentioned that the establishment of the factory in Vietnam was successfully executed completely digitally from Sweden owing to the increase in usability by the no-code elements, which proved advantageous due to the occurrence of the Covid-19 pandemic. The establishment of the sites abroad did only take 1-1,5 weeks, indicating a fast adoption of the no-code MES. The ability to make swift adjustments in their dashboards based on input from the operators is a key feature for Company 1 as well. These findings indicate that a no-code MES enables the companies to be agile as they can effectively respond to changing conditions while also minimizing non-value-added activities. Furthermore, the ability to control the physical production process from a distance indicates that MBrain as a no-code MES provides a DT in the production facility, as there is bi-directional communication between the digital and physical environment (Kritzinger et al., 2018). Despite that, this study only investigates one no-code MES solution, MBrain. It can not be concluded that every such solution will act as a DT, but thanks to the agile and efficient adaptations by the no-code elements will facilitate in creating a DT. It can however be concluded that the no-code MES will bring operational benefits in increased agility and control of the manufacturing companies' operations by adopting such a solution.

Table 7: The table summarizes the identified advantages that can be achieved by adopting a no-code MES solution, and which advantage that can be related to either, or both, the MES or no-code elements.

Advantages	MES	No-Code
Paperless factory	X	
Reduced carbon footprint	X	
Reduced lead time	X	X
Agility		X
Quality	X	X
Real-time data gathering	X	
Traceability	X	
Increased control	X	X
Personnel productivity	X	X
User-friendliness		X
Predictability	X	
Cost effectiveness	X	X
Easy-to-maintain		X
Increased focus on value creation		X
Flexibility	X	X
Eliminates non-value adding manual labor	X	X

6. Conclusions

As discussed, the findings in this study show that a no-code MES will result in beneficial operational and financial outcomes by supporting digitalization, visibility, transparency, and predictability. The no-code MES improves the operations of manufacturing companies by facilitating the personnel to be more productive as the system contributes to a paperless factory, eliminates manual data acquisition, and reduces data entry time. Eliminating the paperwork will result in less consumption of natural resources and will support sustainable manufacturing. Thus, companies implementing a no-code MES can achieve the beneficial operational outcomes of reduced lead times, better conditions for quality efforts, increased flexibility, and agility. These operational outcomes will positively affect the financial performance but will take more time to be realized. It can be concluded that the benefits to the companies' finances are savings in costs related to paper, flexibility, onboarding, and quality which are expected to increase over time.

Additionally, the no-code features eliminate the requirements for significant capital investments and technical skills typically associated with traditional MES. Implementing a no-code MES is a cost-effective measure to take in order to achieve competitiveness for manufacturing companies. This concludes that implementing a no-code MES will bring the same beneficial outcomes as a traditional MES but can be implemented faster and at a lower cost. A concluding remark is that a no-code MES is an attractive alternative to traditional MES for firms that wish to remain competitive in the market.

6.1 Theoretical Contributions

This thesis contributes to the field of science by unifying MES with the existent subject of LCNC. This study creates a deeper knowledge by merging science with empirics and contributes to the development knowledge in this unexplored concept of a combined no-code MES solution.

6.2 Practical Contributions

The no-code MES are proven to be easier, faster, and cheaper to adopt compared to traditional MESs which makes it an attractive alternative. Firstly, compelling evidence suggests that a no-code MES offers a potential solution for companies facing challenges due to the upcoming shortage of software developers. Secondly, by overcoming the limitations associated with traditional MES solutions, a no-code MES proves to be cost-effective and easy-to-maintain, thus enhancing its value as a solution which can benefit SMEs competitiveness in the market.

6.3 Limitations & Future Research

This study has been limited to only investigating two separate case companies, Company 1 and Company 2, and by conducting three interviews. Future research should involve more companies from different industries and include a larger number of respondents for a more comprehensive analysis. Another limitation of this study is that Company 1 and Company 2 only has used the no-code MES for a couple of months. This has meant that the financial outcomes could not be fully investigated into this study's findings that the financial performance will take more time to be realized. In order to be able to prove the financial outcomes fully, further research is needed to confirm the conclusions in this thesis. Quantitative research can be conducted using multiple adopters to make general conclusions regarding the operational, financial and sustainability outcomes from the implementation of a no-code MES.

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Appendix

Appendix 1. Interview Questionnaire

Topic 1: How Mbrain is used

- a. Can you describe how you use MBrain today?**
- b. When did you implement MBrain in your production?**
- c. How did you work before MBrain?**
- d. What do you think are the differences between MBrain and your previous system/way of working?**
- e. What was the main reason why you implemented Mbrain?**

Topic 2: MES built on No-Code

- a. How do you benefit from the fact that the system is built on No-Code?**

Theme 3: MBrain's impact Operationally, Financially, and in terms of sustainability.

- a. Do you have any operational measures/goals you work towards in your production?**
- b. Has Mbrain affected the fulfillment of the measures/goals?**
- c. Can you tell us if MBrain has affected your lead times?**
- d. Can you tell us if and how MBrain has affected your quality?**
- e. Can you tell us if and how MBrain has affected your flexibility?**
- f. What financial savings/opportunities/advantages do you think MBrain provides?**
- g. Can you tell us how the implementation of MBrain affected you from a sustainability perspective?**