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Enterprise Integration as a Driving Factor for Guiding Digitalization in a Manufacturing Small and Medium Enterprise

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Abstract. In the face of rapid technological advancements and evolving consumer demands, businesses increasingly turn to digitalization to remain competitive and redefine industry standards. This article delves into the crucial role of enterprise integration within the context of digital transformation, with a specific focus on manufacturing Small and Medium Enterprises (SMEs). Based on fieldwork within the Innovation Factory North project in Denmark, the study presents a three-dimensional framework – architecture, capabilities, and governance – that is instrumental in guiding manufacturing SMEs through the complexities of digitalization. The architecture dimension explores the dichotomy between monolithic and fog (edge) architectures, highlighting their respective merits and challenges. The capabilities dimension introduces the concept of operational capability stacking, demonstrating how specific information systems, when integrated, yield new capabilities. A list of common capabilities in manufacturing enterprises is provided, offering inspiration for manufacturing SMEs to enhance their operational efficiency. The governance dimension injects a strategic dimension into the digitalization process, emphasizing the need for a balanced approach between technology-driven and process-driven optimization methodologies. The research underscores the strategic nature of digitalization in manufacturing SMEs, recognizing the interconnectedness of architecture, capabilities, and governance in achieving sustained success in the digital landscape. The proposed three-dimensional framework is substantiated through real-world applications within Denmark's Innovation Factory North project, providing tangible insights and scenarios to navigate the intricacies of the digital landscape effectively.
Keywords: Enterprise Integration, Capabilities, Architecture, SME, Digitalization.

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1 Introduction

In the contemporary landscape of rapid technological advancements and evolving consumer demands, organizations increasingly prioritize digitalization as a means to remain competitive, revolutionize their methods of operation, and redefine industry standards [1].

At the heart of this transformative journey lie the concepts of Cyber-Physical Systems (CPS), Internet of Things (IoT), Digital Twin, Big Data, and, among others but no less important – enterprise integration, a strategic approach that intertwines disparate components of an enterprise's technological ecosystem into a unified and harmonized whole. As businesses embrace digitalization, they are confronted with a multitude of challenges ranging from data silos and compatibility issues to complex workflow bottlenecks [2]. The concept of enterprise integration can address these challenges by facilitating the flow of information across diverse platforms, enabling real-time decision-making, and creating an environment conducive to the rapid development and deployment of new solutions. Manufacturing small and medium-sized enterprises (SMEs) often face challenges in implementing enterprise integration due to their low technological maturity, limited financial resources, and lack of expertise and skilled personnel. Unlike larger enterprises, SMEs might struggle to allocate dedicated time and resources to strategic planning for digital initiatives, as they are often preoccupied with day-to-day operational concerns.

This research article delves into the pivotal role that enterprise integration plays in driving digitalization efforts. It presents a three-dimensional framework resulting from fieldwork with manufacturing SMEs in Denmark to guide practitioners to more resolute action. The article aims to create a strategic model to enable enterprise integration and digitalization in manufacturing SMEs.

The rest of the article is structured as follows: Section 2 presents the background of digitalization and enterprise integration concepts, Section 3 presents the methodology, Section 4 presents the three-faceted model for enterprise integration, followed by Section 5, where inspirational scenarios are presented, and concluding with Section 6.

2 Background

2.1 Digital Landscape

The inception of digitalization traces back to the emergence of computers; however, its acceleration occurred with the advent of the Internet. What began as the digitization of information and automation of manual processes has morphed into an interconnected transformation where technology permeates every facet of a business.

The industrial landscape uses digital terms interchangeably; however, the academic world defines the differences between the related terms. *Digitization* refers to data being encoded into a digital format to be used by a computer [3] or a change from an analog task to a digital task. *Digitalization* refers to the alteration of business processes through the use of digital technologies, usually creating new value [4]. *Digital transformation* refers to companywide change, sometimes leading to new business models [5]. For this research purpose, Vial's [6] definition will be used: "a process that aims to improve an entity by triggering significant changes to its properties through a combination of information, computing, communication, and connectivity technologies."

Digitalization is driven by multiple factors, both external (customer demand, supply chain, innovation push, market pressure, and laws/government) and internal or organizational (employee support, process improvement, workplace improvement, vertical integration, management support, horizontal integration, and cost reduction) [7]. All the organizational drivers are, in essence, the strive of the enterprise to remain competitive by improving the aspects that they are most in control of, mainly the business process, technology, and services. Two of the drivers are vertical integration and horizontal integration, which are facets of enterprise integration popularized by industry 4.0 topology [8], meaning that enterprise integration is a driver of digitalization.

2.2 Enterprise Integration

Enterprise integration (EI) plays a very important role in the digitalization journey [9], [10], [11], the perceived importance of industrial practitioners and academic circles is low, and the actions taken are disproportional to their importance [12]. Enterprise integration has a vast research history, starting in the 1990s as the continuation of computer-integrated manufacturing (CIM) and pivoting drastically at the beginning of the 2010s with the advent of Industry 4.0 [13].

Enterprise integration refers to the process of combining various data points from seemingly separate databases and software applications, normally in the form of information systems (IS), to create a seamless flow of data and processes across various departments and break down information silos within an enterprise or even within a business environment. This enables interoperability, which is the ability of systems within an enterprise to exchange both data and services and interpret information to operate together and solve common problems [14].

2.3 Manufacturing Small and Medium Enterprises

Manufacturing Small and Medium Enterprises (SMEs) represent a crucial segment of the industrial landscape, playing a pivotal role in national economies worldwide. These entities are typically characterized by their relatively modest scale, differentiated from larger corporations by various parameters, including employee headcount, revenue, and asset base [15]. The European Union defines brackets of micro (1 to 9 employees), small (10 to 49 employees), and medium (50 to 249 employees) sized enterprises with an annual turnover not exceeding 50 million EUR [16].

A common trait of SMEs is their agility and adaptability, which often enables them to respond more swiftly to market dynamics and innovation [17]. In scientific literature, SMEs are a subject of significant interest, as their unique challenges, such as resource constraints, technological maturity, and limited access to capital, require tailored solutions to enhance their competitiveness and sustainable growth.

2.4 Digital Diffusion in Manufacturing SMEs

The diffusion of digital technologies has been quoted as one of the reasons for weak productivity performance in the last two decades [18], with advanced digital tools and applications differing significantly across countries and services [19]. The manufacturing aspect may also significantly distinguish an SME from other business service enterprises (e.g., those that provide entertainment, consulting, software, marketing services, etc.). Common sense dictates that some services are easier to scale and replicate with information technology than manufacturing, which implies that digital technology diffusion will be slower in manufacturing SMEs. This creates an interesting phenomenon that positions manufacturing SMEs as the “late majority” in terms of diffusion of innovation [20], implying that manufacturing SMEs “should use digital technologies strategically to achieve market success” [21]. This research is an effort to discover the optimal strategy suited for manufacturing SMEs to find and adopt digital technologies with a focus on enterprise integration to increase their competitiveness and make them future-ready.

3 Methodology

This research article is based on findings that were obtained through extensive fieldwork within the Innovation Factory North (IFN) project. Innovation Factory North is a research and innovation hub focusing on supporting SMEs in the Northern Denmark region with their digitalization journey. The project was divided into three distinct stages, as shown in Figure 1. (see [22], [23] for a detailed explanation of IFN structure and methodology).

Figure 1. IFN Project Stages

Awareness: In this stage, the enterprises were introduced to key concepts such as digitalization, Industry 4.0, cyber-physical systems, and digital twins. This acted as an accelerated course, helping them identify areas for improvement. The companies developed a vision for the future that would serve as the TO-BE model. Using a maturity assessment [24], they identified their current state, which would serve as their AS-IS model. Finally, they brainstormed methods for bridging the gap from AS-IS to the TO-BE state. The data gathered from this stage was: (1) the company vision presented through a 1-page detailed description and (2) the maturity assessment [24]. Forty-four enterprises successfully participated in this stage.

Demonstrator: In this stage, the enterprises could explore technology in a controlled environment and consider how those technologies could be implemented at their facility, as well as the impact they would have. The demonstrators were divided into themes: Data-driven decision-making, paperless production, machine learning, digital product models, and UX-driven development. Twelve enterprises successfully participated in this stage.

Anchoring: This stage focuses on helping enterprises implement the demonstrated technology at their facility through technology implementation and change management strategies. The data gathered from this stage was in the form of minutes from unstructured interviews discussing the difficulties related to technology implementation. Four enterprises successfully participated in this stage.

Each stage consisted of three to five workshops, depending on the stage. During each workshop, an expose phase was planned for presentation and discussion, which was either transcribed, video recorded, or detailed minutes taken of it. At the end of the stage, interviews were conducted to assess the obstacles, enabling factors, and details about their environment that were still unclear after the stage. The data collected during these activities was then organized both for quantitative and qualitative analysis.

The quantitative analysis is in the form of a maturity model following Colli et al. [24]. It was used to categorize the maturity of participants in 5 dimensions: (1) Technology, (2) Value Creation, (3) Connectivity, (4) Competence, and (5) Governance. There are six levels for each dimension: ***None***, ***Basic***, ***Transparent***, ***Aware***, ***Autonomous***, and ***Integrated***; they correspond to the ratings 0–5 (For details on how the maturity levels are classified and how the assessment is performed, see [24] Section 4.2). The initial data synthesis (presented in Table 1 and Figure 2) suggests that manufacturing SMEs are generally situated between the ***basic*** and ***transparent*** levels, with more advanced enterprises being exceptions to the rule. A generic description of the state regarding each dimension is as follows: Technology – Digital processes are set up and operative, with some interfacing between the systems; Value Creation – Data is collected and shared for specific processes; Connectivity – The IT infrastructure is not standardized, with multiple IS that can sometimes interface; Competence – The training and learning activities are proposed and carried usually form external source; Governance – There is willingness to digitalize from the management, with some vision in place, but lacking any concrete plans.

Table 1. Synthesis of maturity assessment data

Formula	Technology	Value Creation	Connectivity	Competence	Governance	Total
MIN	0	0	0	0	1	0
MAX	3	4	4	4	4	4
Median	2	2	1	1	1	1
Average	1.66	1.64	1.66	1.45	1.48	1.58
No. of 0	2	2	1	1	0	6
No. of 1	18	19	23	26	29	115
No. of 2	17	17	12	14	10	70
No. of 3	7	5	6	2	4	24
No. of 4	0	1	2	1	1	5
No. of 5	0	0	0	0	0	0

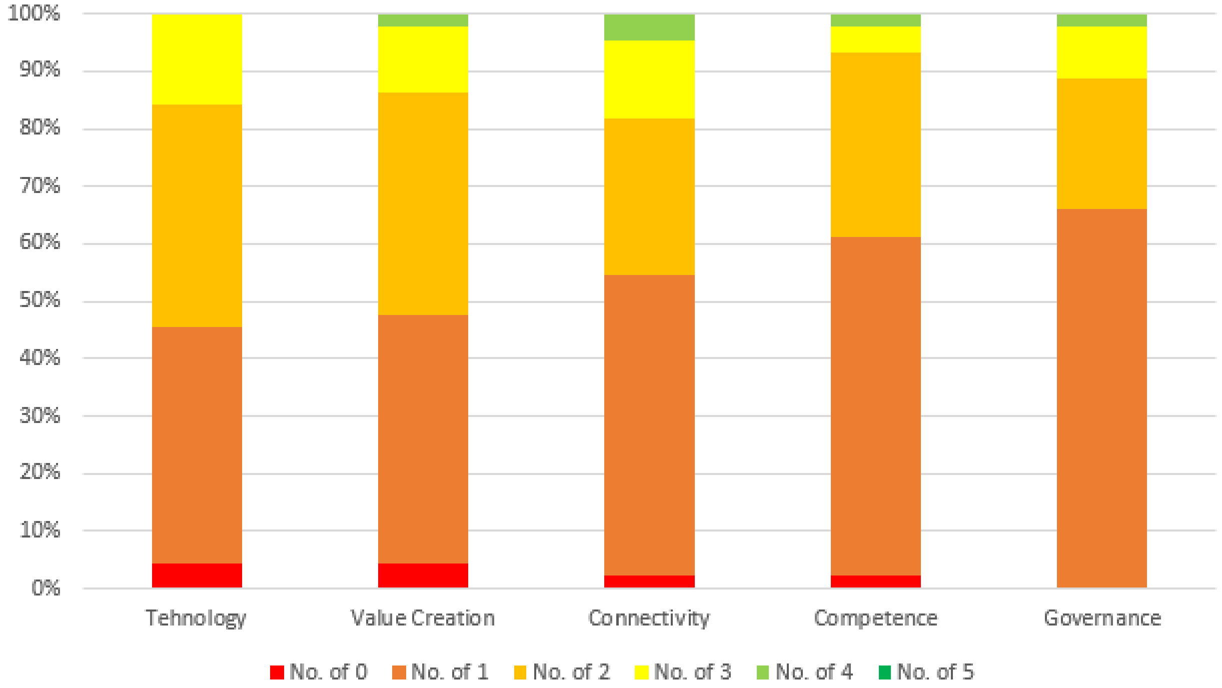

Figure 2. Stacked chart representation of the maturity levels

This suggests that manufacturing SMEs are more often than not at the beginning of their digitalization journey, and the discussion of complex tools or concepts is redundant as it does not lead to practical change. However, specific concepts were extensively discussed, and the participants' interest in the Awareness and Demonstrator stages was provoked. The data of a qualitative nature, collected through the minutes during the workshops and interviews, were formulated to answer the following questions (in relation to enterprise integration):

- Which information systems are implemented at your facility? (ERP, MES, CRM)
- How are they interfaced?
- How and by whom is the information system used?
- Which information system is lacking?
- What concrete capabilities are present (order management, resource management, process visualization, etc.)?
- What capabilities are they missing (to achieve their vision)?

The data was consequently coded using NVivo software for the double purpose of thematic analysis and narrative analysis. The thematic analysis was based on the twelve participating enterprises to deduce the repeating themes and find insights into those underlying themes, and the narrative analysis was for outlier themes to get a deeper understanding of their specific perspectives and issues. The resulting themes were then grouped into three dimensions, presented in Figure 3, that create the core of the framework: ***Architecture, Capabilities,*** and ***Governance***.

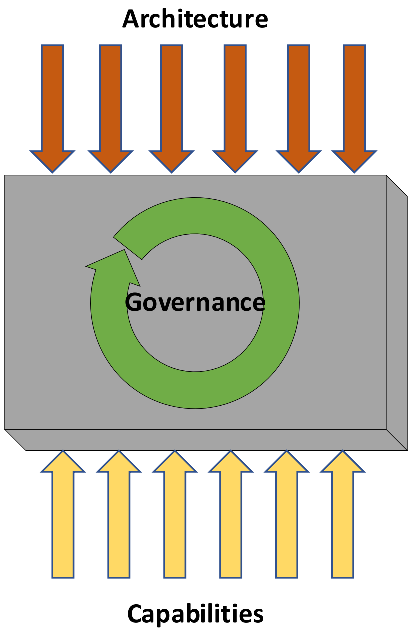

Figure 3. The three-dimensional framework for holistic digitalization with a focus on enterprise integration

Although the framework was not validated in its entirety, it was validated in a segmented way in the IFN project by observing the benefits it brought to participants. The benefit was measured through the interest that it boosted within the workshops (the amount of time it was discussed), the importance assigned to it by the participants (during the workshop), and the impact it had after the project (found through post-mortem interviews).

4 Enterprise Integration/Digitalization Framework

The framework encompasses the three dimensions that present a clear understanding of how one can model and execute an enterprise integration/digitalization project. The first dimension is ***architecture***, which distinguishes between monolith-structured architecture and fog (edge) architecture. The second dimension is ***capabilities***, where we present the concept of operational capability stacking and present an example of it. The third facet is named ***governance,*** where we present the scientific concepts and relevant findings to strategic thinking and methods for conducting enterprise integration.

4.1 Architecture

Enterprise information system architecture encompasses the foundational framework that defines how a system is structured and behaves and the components within it. In the realm of enterprise integration, two distinct architectural models take center stage, each with its own set of characteristics and implications. The first model is the conventional monolithic architecture, which has long been the industry standard and is well-documented in such frameworks as ISA-95 and ISA-88 (see Figure 4). Nonetheless, despite being thoroughly researched and explained, manufacturing enterprises continue to grapple with the complexities of this model, often owing to the rapid evolution of technology capabilities.

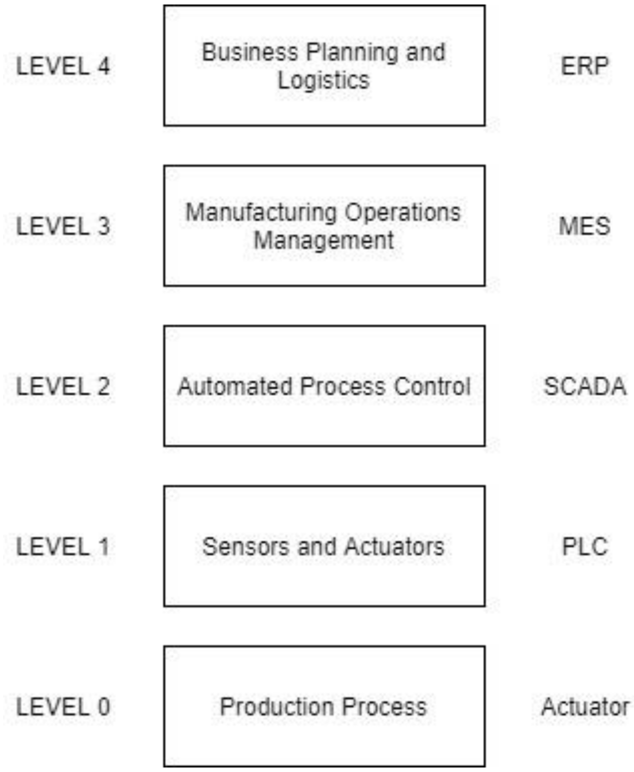

Figure 4. Automation pyramid ISA-95, adapted from [25]

Scholten's work "The Road to Integration" [25] provides insights into bridging integration gaps between different levels within the enterprise, shedding light on the challenges that persist despite the established knowledge. The Manufacturing Execution System (MES) has also garnered considerable attention from the scientific community, particularly in adapting to the demands of connectivity in the modern industrial landscape. In contrast to ISA-95, Koerber *et al.* (2018) [26] propose a vision of the future of vertical integration, envisioning a platform where applications such as ERP, CRM, BI, and analytics are decentralized yet interconnected (see Figure 5).

The monolithic architecture is advantageous in its simplicity and proliferation. It is typically tightly integrated and offers manageability and scalability both vertically and horizontally, as well as simplifying security measures. However, it falls short in flexibility, which is becoming one of the most important factors for competitiveness in the present environment [27]. The frequent changes in technology may necessitate significant system-wide modification, posing a challenge, and a single central component makes it susceptible to a single point of failure, potentially rendering the entire system inaccessible [28], [29].

On the other end of the spectrum lies the emerging paradigm of fog computing/edge architecture. It represents a radical departure from the traditional monolithic architecture, arising from the need to keep pace with the rapidly expanding computing capabilities. This model embraces a decentralized and distributed approach, effectively moving computational power to the edge node of the network, ultimately enhancing real-time responsiveness and ensuring low latency responses [30], [31], which is crucial for IoT applications and time-sensitive control tasks [32]. Nevertheless, edge architecture presents complexities in managing and coordination, as well as security. Moreover, the maintenance and scalability of edge nodes can be cumbersome and expensive [33].

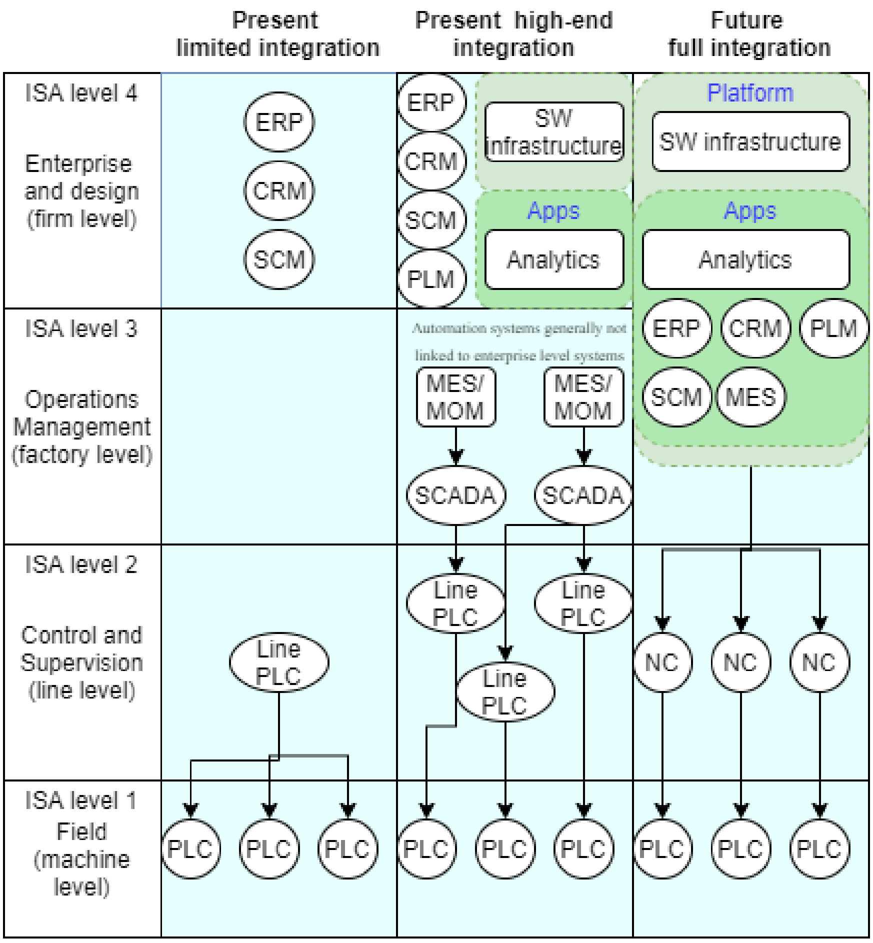

Figure 5. Vertically integrated enterprise, adapted from [26]

Nevertheless, one should not subscribe to a one-size-fits-all approach. Striking a balance between both architectural models is entirely reasonable. This involves deploying a central database and computing resources for resource-intensive tasks such as data analysis and machine learning, whether in the cloud or physical data centers. Simultaneously, edge nodes come into play for time-sensitive and lightweight computing tasks like logic controllers. In practice, these components have distinct roles and responsibilities, and combining them offers a more versatile and capable system than relying solely on one model or the other.

Considering Enterprise Architecture within a digitalization project would ensure that the enterprise has a grasp on the IS infrastructure while growing and safeguarding itself from future states where digital technologies are disconnected and do not follow the same vision for the company.

4.2 Capabilities

In the context of a manufacturing enterprise, capabilities refer to the collection of skills and competencies that the organization possesses to perform its business processes. They can be enabled or automated by technology like information systems and grouped to perform orchestrated operations that yield more value. The concept of capabilities is gaining traction in the scientific literature on account of its importance to development. Forsgren et al. [34] argue that focusing on capabilities yields the most value for the growth of the company, while Danesh and Yu [35] argue that using capabilities mapping is more accurate and usable for manufacturing enterprises than maturity matrixes and assessments.

In this article, we will list the most common capabilities, link them to information systems, and explain how integration between specific information systems can evolve a new capability using the stacking effect through scenarios. Figure 6 presents an example of capability stacking where the accurate "planning and scheduling" capabilities are the result of having downstream capabilities such as resource overview and accurate process cycle times, which are in turn stacked on top of other capabilities. We observe three different columns that represent distinct starting points for capability stacking. The left-hand side (Digital Product) means when the design and development of a product is done with the help of an orchestrated computer-aided program (CAD). On top of this, the automatic eBoM (engineering Bill of Materials) and then mBoM (manufacturing Bill of Materials) can be derived. The mBoM has information about the BoP (Bill of Processes) which can be fed into a system to automate more precisely the planning and scheduling of orders. The second column is related to ERP and resource management. The base of the column represents having an overview of the personnel, on top of which one can map their capabilities related to manual work, as well as knowledge and skills. With this explicit knowledge the assignment of tasks is improved and the process of finding a substitute when personnel are sick is automated. One can also track the work through IT if the underlying capabilities are put in place. The third column represents the information about machines and processes. One can use IoT to gain visibility on the production floor and calculate more accurately the process times and cycle time. These three capabilities coupled can automate/enable faster planning and scheduling. Capability stacking took inspiration from general systems theory [36], and more concretely from the emergence effect, where the interrelation between entities create new features/agencies/characteristics for the broader system of interest.

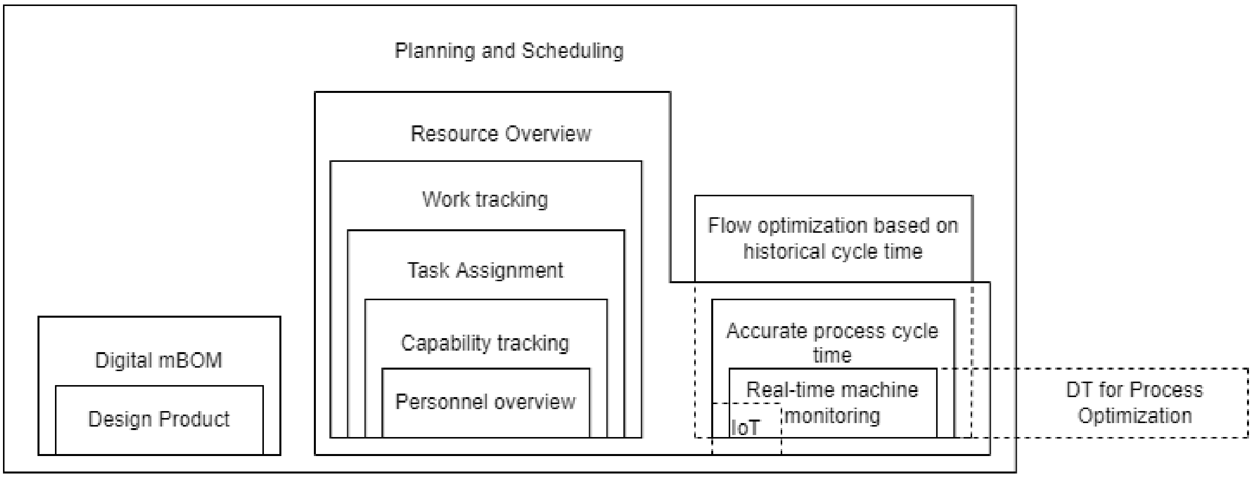

Figure 6. The stacking effect of operational capabilities

Operational capabilities refer to capabilities that enable specific automated tasks within the operation in a manufacturing environment. As part of IFN data gathering, specific operational capabilities were identified in the Awareness and Demonstrator stages. Thematic analysis was done by counting how many times the participants mentioned these capabilities and the time spent discussing them. It is not meant to represent a full list but rather the most common capabilities that manufacturing SMEs would and should target and the associated technology and/or methods. The discussion tended to flow toward simpler capabilities, which is explained by the low level of technological maturity of the participants.

- Resource (equipment, personnel) management (ERP); mentioned 125 times by almost all the participants 39/44.
- Order management (ERP) of little interest because all the participants had it implemented. It is considered essential.
- Capacity planning (ERP), mentioned 87 times by more than half the participants 29/44.
- Inventory management (WMS), mentioned 52 times by roughly half the participants 21/44.
- Customer management (CRM), mentioned 66 times by some participants 18/44.

- Asset tracking (ERP/WMS + RFID), mentioned 73 times, garnered special interest by some participants 23/44.
- Real-time control of the production processes (Manufacturing Execution System MES), mentioned 98 times by most of the participants 33/44.
- Real-time overview using IoT, mentioned 150 times by all participants 44/44.
- Digital product development, design, and engineering (Computer aided design CAD), mentioned 30 times by a group of participants 8/44.
- Product version control (PLM), briefly mentioned 21 times by some participants as part of other conversations 5/44.
- Prototyping (PLM + CAD + parametric design), mentioned 71 times by most participants 35/44.
- Process optimization (BPM / Lean manufacturing), mentioned 40 times by some participants 17/44.
- Product flow optimization (discrete-event simulation/resource behavior modeling), mentioned 43 times by some participants 20/44.
- Mass Customization (CRM + CAD), mentioned 67 times by most participants 29/44 as being too out of their reach.

This list should inspire manufacturing SMEs to develop their capabilities through the stacking effect by either implementing a new technology or fully using an existing one, implementing a new methodology, or using an existing capability to enable another one. As is colloquially said, there are many low-hanging apples that can be plucked. It is about identifying them.

To ensure that the correct capabilities are created, we recommend using the correct methodology (DevOps was shown to successfully help manufacturing digitalization projects [37], [38], [39]) and engaging the blue-collar workers, operators, or other users of potential digital solutions).

4.3 Governance

To gain the mentioned capabilities, one needs to ensure that they have all the required prerequisites. Is the workforce ready to embrace the new technologies or change their business processes? Is there knowledge to develop the technology or money to buy a proprietary solution? Is there an implementation plan and use plan?

There is not a single *best* way to do it, but rather a one-dimensional spectrum where on one side it is a technology-driven methodology (which corresponds to the architecture dimension), and on the other is process-driven optimization (which corresponds with the capability dimension), as presented in Figure 7.

Figure 7. Technology vs. Process Optimization Driven methodology

Normally, enterprises that follow the top-bottom mentality choose a vendor and buy a proprietary solution. All the big vendors of EIS (Enterprise Information Systems), like SAP, Microsoft, Dassault, etc., are expanding their products to cover many functions and enable more capabilities for their clients [40]. There, however, is a downside to this approach, and mainly that a company is restricted by the solution they bought. These solutions are hard to integrate because the proprietors do not prioritize integration into their products.

On the other spectrum are companies that follow the bottom-up approach. They normally have a dedicated optimization team, be it in a digitalization or strategy department, and use methodologies like DevOps to improve their business processes. They use in-house-developed solutions that perfectly fit their needs. SMEs, however, do not have the financial and knowledge capacity to be picky about their solutions. They are characterized more by their need to extinguish fires rather than build a fireproof house.

Two distinct theories concerning digital transformation should be considered. Dynamic capabilities theory posits that, alongside operational capabilities needed to sustain an enterprise, there are other capabilities that drive incredible value [41]. These normally refer to capabilities that facilitate strategic change, be it organizational or technological [42]. The often-mentioned dynamic capabilities are the absorptive capacity, innovation culture, and continuous learning and development [43].

Ambidexterity theory, also mentioned as a dynamic capability, refers to the capability to balance the exploration of new technologies, concepts, and methods to be future-prepared and the exploitation of existing internal resources to increase competitiveness [44]. Ambidexterity is especially important for companies that face resource scarcity [45], which is normally a characteristic of manufacturing SMEs. The capability stacking process presented in Section 4.2 “Capabilities” follows this logic.

We argue that one can position oneself in the middle range of the one-dimensional spectrum (Figure 7) and maximize the chance of success of a digitalization project by using the postulated theories coupled with the three-dimensional framework. Ambidexterity theory can be used to balance exploration with exploitation, thus mitigating risk while keeping the day-to-day operations floating. The dynamic capabilities can help maximize the chance of success of innovative projects by fixing the culture ahead of time. The Architecture dimension provides the needed knowledge and ensures the correct direction of digitalization projects, while the capability dimension ensures the needed capability is developed in the correct manner and time.

5 A Vision for Manufacturing SMEs

Two scenarios were created to illustrate how the presented model and concepts can be used. These scenarios are based on real cases identified in the IFN project. The scenarios have been influenced by the vision of a smart factory, which is explained further.

A smart factory is an engineered complex system that is composed of multiple systems like EIS, CPS, Digital Twin, or other digital technology, which in themselves are composed of subsystems of similar technologies. The system, at any level, is characterized by a clear boundary with interfaces to the outside, components that can be systems in themselves, and a scope. An effort is made to map an overview of the systems that comprise a Smart Factory by mapping the scope of each system and how they are related to other systems (see Figure 8).

The figure differentiates functions in 4 dimensions: (1) Sales and Marketing; (2) Warehouse Management; (3) Engineering and Planning; and (4) Operations. Presently, in most companies, these functions (and many others) are done manually, but there is a possibility of automating many with integrated EIS capabilities coupled with new technologies.

5.1 Scenario 1: Request Quotation for a New Customized Product

This scenario deals with automating order details when a customized product is required. Figure 9 presents the value chain for this scenario. We can observe that the full action requires multiple engagements with the customer, for approving the requirements, approving the product design, and approving the delivery date, and one engagement with the supplier. All these interactions are time-consuming and bring little value due to high waiting time.

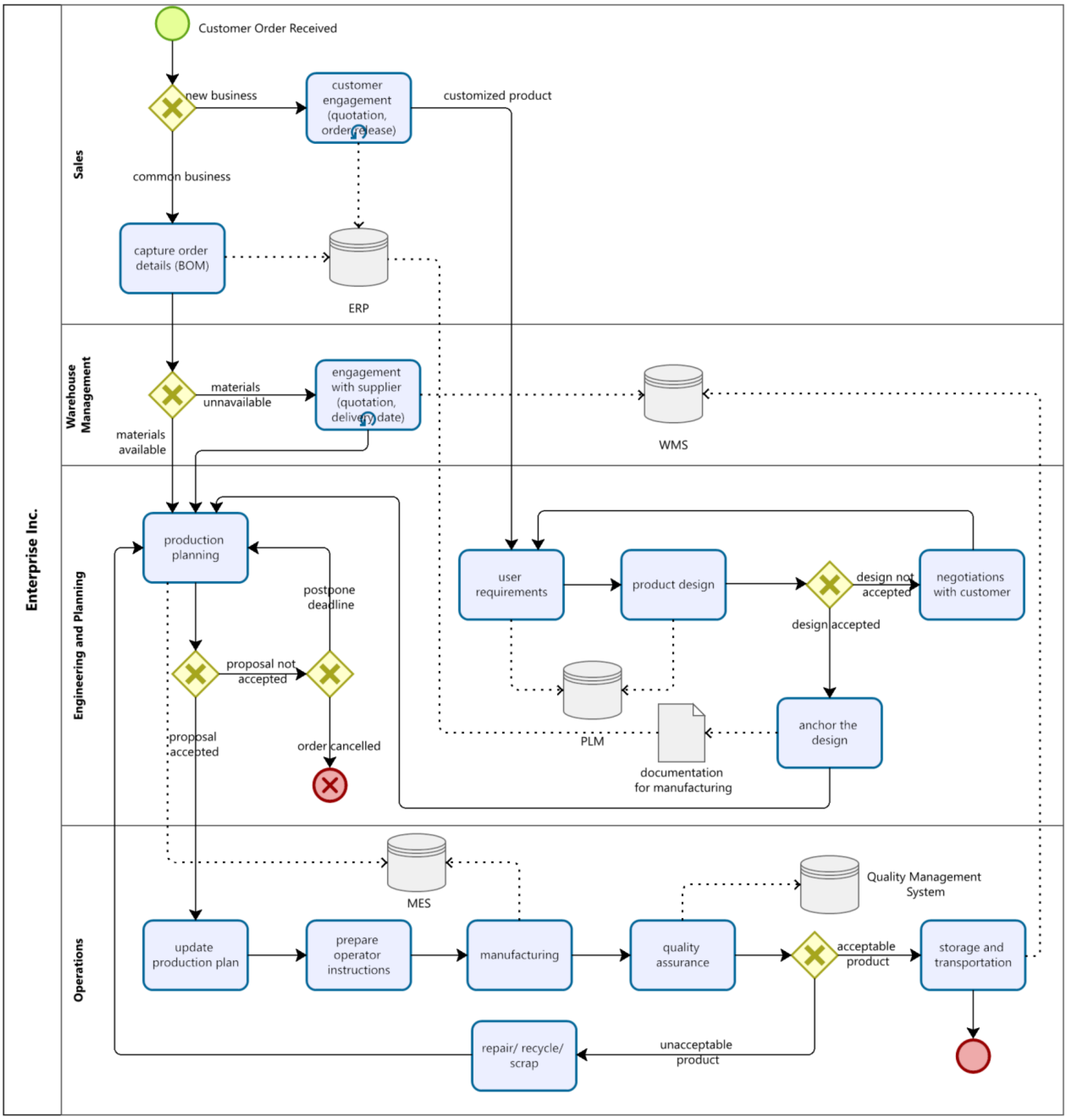

Figure 8. Value chain map for smart factory

It is possible to automate the whole process by implementing additional technologies. For instance, the synthesizing of user requirements and creation of product design may be automated with the use of a product configurator, with the prerequisite of integration between ERP (for resource overview) and PLM (for product attributes overview), while prototyping is done through the use of additive manufacturing with the help of CAD, PLM, and ERP. The production planning can be automated through a proprietary technology with the prerequisite that one has accurate and real-time information about needed resources (machinery, personnel, etc.). The engagement with suppliers can be improved by applying horizontal integration.

By integrating all the mentioned tools, we can further automate the process, potentially diminishing the throughput time to only what the production requires. To do that, we have a gradual implementation of technologies that can enable even more capabilities while integrated and working in tandem.

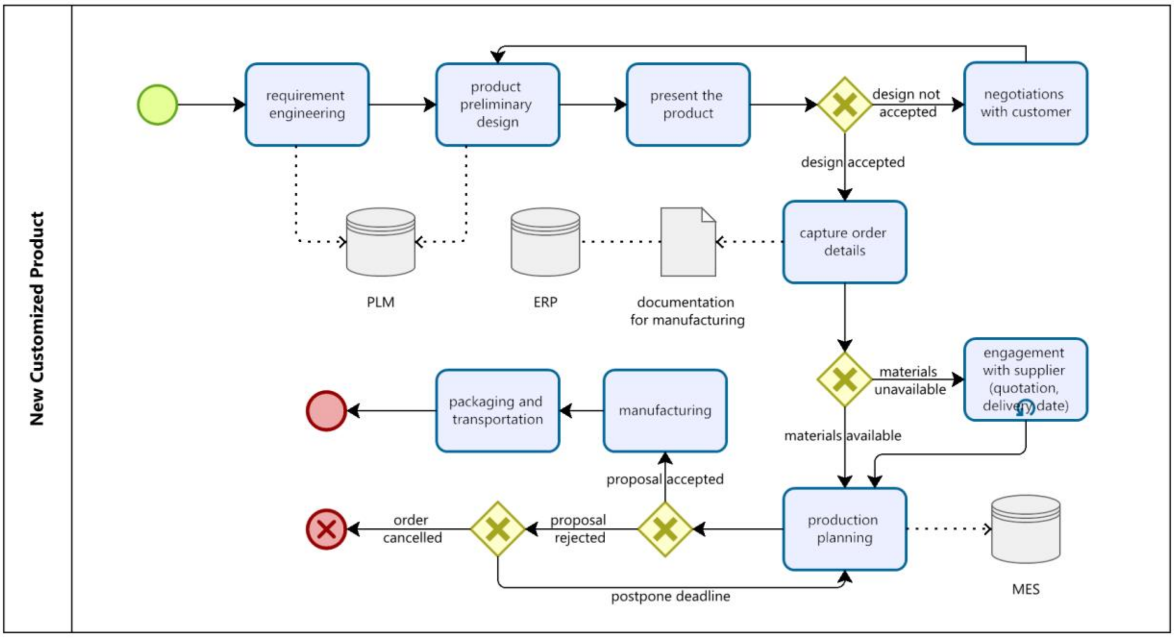

Figure 9. Value chain map for request quotation for a new customized order

5.2 Scenario 2: Re-planning for Urgent Order

Sometimes orders are lost because an enterprise cannot re-plan for urgent orders. Figure 10 presents the value chain map for such a situation and how it can be handled. When an urgent order is received, the order details are captured, and the availability of materials is assessed. Next, the scheduling is assessed to determine if there is a possibility of executing the order without postponing other orders. That is usually not the case, so the next step is to find the bottleneck and adjust the planning for other orders to minimize the consequences. Sometimes, this will be possible while keeping to the delivery deadlines provided by the customers; otherwise, the sales team should engage with the customers and present the new delivery date. If the customer accepts the changes, one can just proceed with the planning and execution. In more cases, the customer declines the new delivery date because it interferes with their planning, and then it is back to making scenarios.

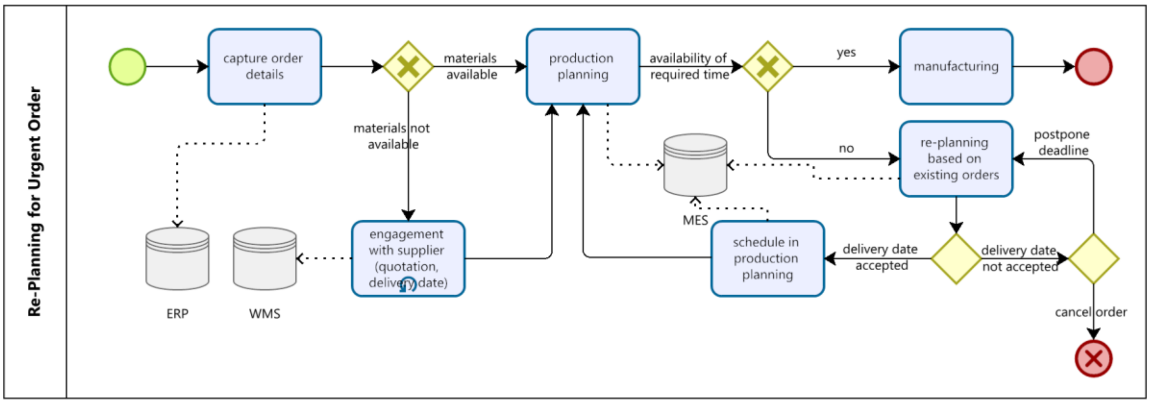

Figure 10. Value chain map for re-planning operation based on urgent incoming order

There are many ways to simplify the re-planning of the production. One is to use a flexible Kanban-based application (e.g., Monday.com, Asana, Miro, etc.) that gets machine status information from the MES and order information from ERP, and manually input and change the blocks or work while looking for a solution. Of course, some operations can be automated, such as identifying the bottleneck, creating scenarios, or even contacting the customer. The presence of operational and data silos is detrimental to the daily operations of a manufacturing enterprise, and these scenarios present how a manufacturing enterprise focused on integration can create capabilities to increase its competitiveness.

6 Conclusion

This research delves into the digitalization landscape within manufacturing SMEs and accentuates the paramount role of enterprise integration in steering their digitalization transformation. The cornerstone of this exploration is introducing a robust three-dimensional framework—encompassing architecture, capabilities, and governance—as an essential framework to guide them through the intricacies of digital transformation. This framework emerges not merely as a theoretical construct but as a pragmatic tool grounded in real-world applications from Denmark's Innovation Factory North (IFN) project.

The framework's architectural dimension scrutinizes the dichotomy between monolithic and fog (edge) architectures, revealing the merits and drawbacks of each. The conventional monolithic architecture, well-entrenched in industrial practices, offers simplicity and manageability but falls short in flexibility. Conversely, the emerging fog computing/edge architecture, while promising real-time responsiveness, presents challenges in coordination and scalability. The article underscores the importance of balancing these models, advocating for a nuanced approach that harnesses both strengths.

The capabilities dimension of the framework unfolds the significance of operational capabilities in manufacturing enterprises. The article establishes a clear linkage between these capabilities and the associated information systems by delineating a comprehensive list of capabilities – ranging from resource and order management to real-time control of production processes. The stacking effect of operational capabilities, exemplified through scenarios, illustrates how integration between specific information systems can birth new capabilities, creating a cascading effect that optimizes manufacturing operations. This dimension is a practical guide for manufacturing SMEs in developing their capabilities and emphasizes the need for a nuanced and strategic approach to technology adoption. The capability stacking effect underlies the role of specific information systems and how they can evolve and change when combined with others. Borrowing from the social construction of technology theory [46], we position that certain information systems have agencies to do specific actions. However, it can be used very differently when separate and when it is combined with other information systems. That is why enterprise integration plays such a significant role in digitalization, it allows agencies to emerge.

The governance facet of the model injects a strategic dimension into the digitalization process. The article unveils enterprises' nuanced choices, emphasizing the relevance of ambidexterity theory and dynamic capabilities theory. It posits that a delicate balance between exploration and exploitation is vital, especially for manufacturing SMEs grappling with resource scarcity. The article points to the DevOps methodology as a potent tool for involving operations in decision-making processes.

In tandem, these three dimensions coalesce into a comprehensive framework that guides manufacturing SMEs through the intricacies of digital transformation. The article showcases its applicability through scenarios, illustrating how the model, when correctly implemented, can streamline processes, reduce throughput times, and enhance the overall competitiveness of manufacturing enterprises. By grounding the model in practical insights derived from the IFN project, the article provides a roadmap for manufacturing SMEs to understand the nuances of the digitalization landscape and navigate it effectively.

This framework differs from classic frameworks like CIMOSA [47] and PERA [48] because it is not result-oriented. This means the framework does not show what the end result is but rather showcases possible improvements within its own constraints and limitations. This is similar to the

Zachman and TOGAF frameworks. However, the proposed framework is simpler and, at least compared to Zachman, promotes a more agile approach to development. TOGAF, on the other hand, although it promotes agility and is focused on continuous improvement, is hard for SMEs to adapt to [49].

While the proposed framework is based on real-world findings in Danish manufacturing SMEs, it still lacks a concrete methodology for adoption. The framework was not tested in its entirety, so there is no data on its full advantage and what kind of impact it can have on manufacturing SMEs. However, the data from partial testing is promising.

In conclusion, the research underscores that successful digitalization in manufacturing SMEs necessitates a holistic, integrated, and strategic approach. The three-faceted framework emerges as a beacon, illuminating the path for enterprises seeking to optimize their digitalization journey by addressing the challenges of architecture, capabilities, and governance in a synchronized and thoughtful manner. As manufacturing SMEs grapple with the demands of the digital era, this framework stands poised as a versatile tool, ready to guide them toward a future where technology integration, operational excellence, and strategic governance converge seamlessly for sustained success in the digital landscape.

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