Towards a Reference Architecture for Planning and Control Services

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Abstract. Producers of manufacturing equipment can, instead of just selling their products, also offer their customers services to increase customer satisfaction, gain competitive advantage, and increase their profits. These goals can be reached by helping the customers optimise their processes and improve their reliability and flexibility. This can be done by supporting the customer that invests in new manufacturing machines with a planning and control tool connecting the machines and the processes between them. More specifically, this will become possible by introducing and integrating active data management and analysis, and planning applications in the current architecture of companies. All of the processes currently being done manually in the customer companies, from monitoring to production planning based on direct observation and the experience of production managers, can be automated using these applications. This paper presents a reference architecture supporting the connection of these processes using the mentioned applications, and validates the developed models based on a real case study of a production machine manufacturer and its customers.

Keywords: Service provision · Manufacturing machines · Reference architecture · Production planning · Data management

1 Introduction

Nowadays, customers prefer suppliers that can provide specific accompanying services to their offering items, not those that sell mere products or equipment [1]. Therefore, a production machine manufacturer that can offer specific and customised services helping their customers in various stages of using their purchased equipment is a priority choice for the customers [2]. Hence, it is logical for equipment manufacturers to start an initiative offering customised services [3]. There are several types of services that companies can offer their customers, helping them in managing their processes in different ways and degrees. Depending on the company, the customers might not like to give full access of their processes to their suppliers and become completely reliant on them. Hence they would be more interested in services offered through the use of software or an artefact helping them with efficient connection and utilisation of the equipment they purchased, aiming to manage and optimise their use [4].

The service provision initiative will result in increased customer satisfaction [5, 6] and also create competitive advantages [7, 8]. Subsequently, from these gains, the

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service provider will get closer to its final goal, increasing the total profit [9, 10]. One of the main ways to support the customer companies by presenting them a service to enhance their experience using the equipment they purchased is by helping them using the equipment efficiently and effectively, increasing the flexibility and reliability of their production systems [11, 12]. One of the ways to define the offering service is that this service will help the customer companies move toward automation and elimination of manual processes as much as possible. This can be done using dynamic and efficient production planning approaches, helping them use their purchased equipment efficiently and effectively [13, 14].

Customer companies can move towards their goals by aligning their business needs and information systems throughout different levels of their operations, aiming to control and optimise their processes. The business question is what kinds of services the service-providing companies should offer to their customers. Also, they should find the best way to offer these services to their customers, supporting the efficient and effective use of purchased machines, helping them to reach their goals in their factory control and optimisation process. In more detail, they can illustrate the expected results of this integration process and how it will affect the current architecture of the customer companies.

The enterprise architecture discipline presents a shared language for building efficient guidelines for such an integration [15]. The shared modelling language encompasses the concepts related to information technology (IT) systems and their applications alongside the physical environment for presenting a blueprint for the integration process, which can be called a reference architecture (RA) [16]. Kruchten [17] defines the RA: "A reference architecture is, in essence, a predefined architectural pattern, or set of patterns, possibly partially or completely instantiated, designed and proven for use, in particular, business and technical contexts, together with supporting artefacts to enable their use. Often, these artefacts are harvested from previous projects." Another definition of a reference model is a conceptual framework that describes a collection of connecting ideas and relationships regardless of specific standards, technologies, or implementations within a specific problem domain [18]. Hence, based on the presented definitions for an RA, this study considers the use of RAs to create guidelines for incorporating a control and optimisation toolbox into the current architecture of customer companies of production machines and analysing its influence on their architecture as the research problem.

This study is structured based on the research methodology for research in information systems suggested by Peffers et al. [19]. The research methodology and how each section of this paper is aligned with the methodology are shown in Fig. 1. The following sections focus on the literature review and the research gap (Sect. 2), motivation and strategy analysis (Sect. 3), model design (Sect. 4), discussion and case study (Sect. 5), and conclusion and further research (Sect. 6).

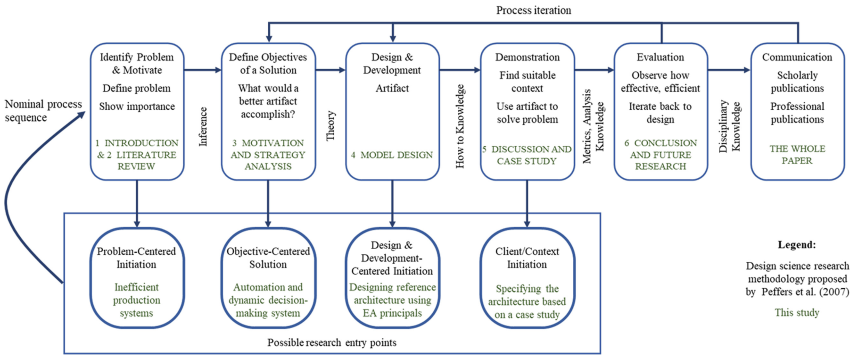

Fig. 1. Research methodology

2 Literature Review

The literature review is divided into two parts: (i) servitisation and (ii) RAs, highlighting the importance of servitisation for companies and the application of RAs.

Servitisation in manufacturing companies is defined as the process of enhancing the capabilities of a company to provide a better experience for its final customers and increasing the revenue streams for both stakeholders by offering specific services [20]. Gebauer et al. [21] performed a literature review focusing on the contributions of the service strategies. They also presented guidelines for managers in manufacturing companies interested in offering services related to the products they sell in several industries. Kohtamäki et al. [22] analysed the correlation between service offering and sales growth. The results, according to the data collected from multiple Finnish manufacturers, showed a non-linear relationship between sales growth and service offering. A study extending the service levels by adding a new type of service to a product-service value chain to increase the long-term competitive advantages of the chain was performed by Opresnik and Taisch [23]. They concluded that this idea would increase the competitive advantages and revenue streams for the service provider and customer. Tenucci and Supino [24] examined the correlation between profitability and different types of product-service systems. The findings of the empirical analysis revealed that when companies focus on both product and service, they have higher profitability than the case of focus on one of them. Zhang et al. [25] analysed the facilitating influence of technology and market orientation strategies on different levels of service provision types relative to variable firm sizes. They conducted an empirical study using survey data confirming that service provision significantly improves the sustainable profile of manufacturers.

Recent studies that designed RAs and highlighted their application are presented in the following. Iacob et al. [26] presented an architecture for a fuel-based carbon emission calculation system collecting real-time data during trips of vehicles using onboard computers. The designed system also integrated the business processes of logistics service providers and typical software applications. Hernández et al. [27] suggested a novel RA to support cooperative decision-making in the supply chain. The architecture was validated through its application in an automotive supply chain where improvements in service levels were observed. An RA addressing customers and business partners in the internal processes of the whole enterprise in the field of service-oriented e-commerce was developed by Aulkemeier et al. [28]. Singh et al. [29] proposed an integration platform RA assisting enterprises in making affirmative decisions regarding integration platform solutions or design. The research did a commonality analysis to select the best practices in integration platform design and act as a reference point for future research.

Verdouw et al. [30] developed an RA to integrate the Internet of Things and logistics information systems in the supply chain of agri-food. Through utilising various technology enablers and supporting the reuse of domain-specific features, the architecture facilitates the supply of affordable tailor-made solutions. Iacob et al. [31] proposed an RA for situation-aware logistics based on the principles extracted from a comprehensive analysis of requirements, literature review, and the prompted idea by the Industrial Data Space initiative. A study proposing an RA that aims to enhance supply chain resilience by relying on Smart Logistics and the Internet of Things was done by Koot et al. [32]. They included a hierarchical set of disruption handling mechanisms to enhance the analysis of the trade-off between response time and decision quality in their model.

Based on the literature review on servitisation, the increasing value of adding services next to offering products by a company in different areas of industry can be highlighted. Also, based on the review regarding enterprise architecture and RAs, it has been noted that having concrete and generalised plans for integrating different principles and processes in a system can enhance the integration process and guarantee its final success. The benefits of adding different types of services alongside the selling products of a company are noted by multiple studies; however, there are no guidelines on how a company can start offering such services to their customers.

The contribution of this research can be highlighted in facilitating the efficient planning and control of production lines, meaning that the study focuses on the successful integration of planning and control services in manufacturing companies using enterprise engineering concepts. To the best of our knowledge, according to the state of the art, there is no guideline such as an RA for this phenomenon. The lack of an RA, used as a guideline for companies that intend to add a planning toolbox as a service to the products they sell, is part of the research gap we are focusing on. Hence, the contribution of this study is designing a reference model for the mentioned phenomenon based on the ArchiMate® 3.1 Specification [33] to fill the existing knowledge gap and integrate optimisation and control approaches, as a part of the planning toolbox, with the company architecture as an active system. The presented models are also validated using a real case study at a manufacturing company of production machines intending to offer control and planning services to their customers.

3 Motivation and Strategy Analysis

An important characteristic of an RA is to act as a reference to ease the communication of a technical design among the stakeholders. This is often accomplished using an abstract representation of the system using architectural perspectives, which show the system in a context relevant to the needs and goals of stakeholders [34]. One of the main challenges in collaborative projects is to convey the main idea and reason behind a collaboration between business and technical stakeholders using different languages [35].

Since the goal is to provide data standards, services, and process plans at the enterprise level, clarity for all stakeholders associated with the architectural definitions and design becomes critical [36]. The ability of stakeholders to have a complete understanding of the potential of each prospective project, next to the ability of the architects of those systems to effectively incorporate business strategies into the architectural design, will determine whether they succeed or fail [34]. An RA should highlight the link between business motivations, strategies, services, processes, and the information to support those strategies and motivations [37].

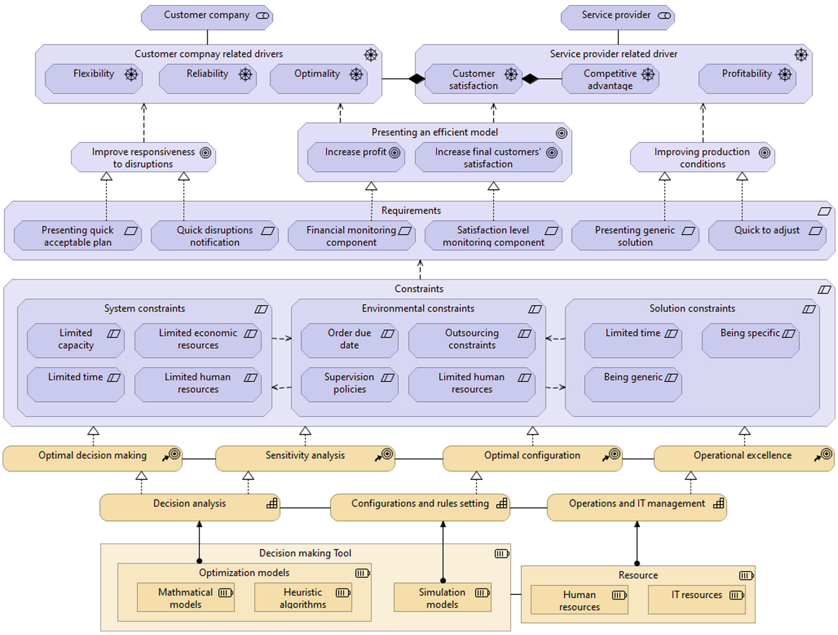

Fig. 2. Motivation and strategy layers

The necessity of designing such a system to provide the required services can be highlighted by presenting the motivation and strategy view of the proposed integration architecture. The motivation and strategy view of this study is presented in Fig. 2. The figure is designed based on literature and interviews with industry managers. According to the name and the colour of the elements in the figure, it can be seen that this view of the architecture is divided into two parts: (i) motivation and (ii) strategy.

The motivation layer consists of the stakeholders, drivers, goals, requirements, and constraints. The stakeholders of the suggested integration are the service-providing company and the customer companies of the service [38]. Each of these stakeholders has their specific drivers in mind to be interested in this integration. These drivers are formed following the requirements that the to-be-designed tool should satisfy. The drivers for the service-providing company are increasing their profit and the satisfaction of their final customers. Increasing customer satisfaction will be achieved by providing a service that helps the customers achieve their own drivers [39–41].

The requirements that should be satisfied by the target architecture are mentioned briefly in Fig. 2, at the fourth level of the motivation and strategy view. The requirements are formed based on interviews with several industry managers from the service-providing company and their potential customer companies, asking them about their needs and then translating them to the requirements the proposed service provision initiative should satisfy [42]. The details of these requirements are mentioned in the following.

- **Present a quick plan:** The system should update the production plan of the customer company in a reasonably short time after detecting a disruption or change in the available data.
- **Quick disruption notification:** A notification should be sent to the workers by the system notifying them of the occurred disruption, so they stop the production process and wait for the updated production plan.
- **Financial monitoring:** The system should have a component analysing the financial conditions of the stakeholders based on each potential decision and consider it in the decision-making process.
- **Satisfaction level monitoring:** The system should evaluate the satisfaction level of all stakeholders regarding each potential decision and incorporate it into the decision-making process.
- **Present a specific solution:** The solution presented by the system should be specific for the case of each customer, so it can be immediately applied without any changes as a countermeasure to each disruption or data change to maintain the efficient state of the production process.
- **Quick to adjust:** The system that will be incorporated into the architecture of companies should be quickly configurable to each customer's situation, making it easier to offer it to many customers.

There are also different types of limitations and challenges in the way of a successful service provision system integration that should be considered in the motivation layer of the architecture. These challenges and limitations are divided into the system, environmental, and solution constraints. System and environmental constraints are enforced by the conditions of the customer company and the conditions, laws, and regulations of different countries or states, respectively. Examples of system constraints are that the company has limited capacity and human resources, which should be considered so the solution presented by the system would not offer to use another machine for a specific process or add another worker to a workstation to finish the job without considering the extra cost and the changes it will impose to the company. Limitations in the availability of the workforce in an area of work in a specific region or not being allowed to use a specific technology or purchase a particular type of raw material are the constraints enforced by the environment.

The solution constraints are associated with the dynamic decision-making software of the target architecture, which guarantee the efficiency of the presented solution [43–46]. For example, being generic and specific means that the software should be generic enough to be configurable for different companies, but have the required configuration parameters, to make it specific for each company.

The strategy layer is divided into resource, capability, and course of action. The required resources for the suggested integration have specific capabilities, which result in the specified course of actions affecting the realisation of the motivation layer. The resources are divided into human and IT resources, assigned to operational and IT management to realise operational excellence [47, 48]. The other part of the resources is the to-be-developed tool assigned to configuration and rule-setting, and decision analysis, realising optimal configuration, sensitivity analysis, and optimal decisions [49–51]. The decision-making tool would work as the primary enabler of this service provision initiative.

4 Model Design

In this section, we first present the baseline architecture, which shows the current conditions of the customer companies of production machines without receiving the offered service. After that, the target architecture is developed based on the presented motivation and strategy view. The target architecture shows how the stakeholders reach their desired goals by adding the control and optimisation toolbox to the enterprise. Table 1 presents the main concepts used in the designed models, accompanied by a short description of them.

Table 1. Definitions of concepts used in the presented model

Concept	Definition
System	All of the components (micro-systems) and processes of the customer company that interact with each other and work to produce the final product
Solution	A complete production plan, consisting of the purchasing of raw materials, production sequences, and scheduling of the processes of the system
Machine	Production machines purchased from the service-providing company, used in the customer company for the production process
Disruption	Any type of event that can halt the production process and requires change of the production plan
Dynamic operation planning	Changing the production plan according to the occurrence of disruptions or a change in order details, which requires an updated plan for maintaining the production process in an efficient state
Model (Technology layer)	The decision-making process used for presenting and updating the solution based on the condition of the system at any moment in time

The presented models are developed based on interviews with production managers of a few collaborating service-providing and customer companies. The focus of the interviews was on gaining insight into the details of the current and ideal collaboration between these companies. Moreover, the discussions revolved around how these companies function in the current conditions, in which areas they require improvements, and the ideal picture they have in their mind for their future production process.

4.1 Baseline Model

The baseline architecture shown in Fig. 3 represents the typical architecture of the control and optimisation process of customer companies that buy production machines without any accompanying services. More specifically, this applies to companies that currently do not have a toolbox for synchronised and real-time monitoring and optimisation of their processes. Hence, these processes are done by the managers of these companies using simple tools based on experience and limited data. These companies have the characteristics of a flexible or hybrid flow shop where the workload between the different stages of the production process should be balanced to have efficient performance. All production stages should be actively connected and share information to achieve maximum synchronisation between the stages, which is absent in the current architecture of our target companies.

The main stakeholders of the control and optimisation application are the manufacturing companies and the final customers of their products. The customer company itself is responsible for operations management and monitoring services. The production planning process is triggered by the production planning application or the disruption detection event. Due to the absence of an advanced real-time data management system, the disruption detection event leads to notifying the managers, and after that, the countermeasure, e.g., in terms of providing materials or performing a repair, is done by operators based on the decision made by the managers. The disruption readiness and system optimisation functions realise the operations monitoring and management services, respectively, enabling the company to serve its final customers.

The data management and production planning application components both function using spreadsheet applications. These applications are responsible for data aggregation and storage, and present production plans, and through that, realise the data and system management services. The data management application has access to order details, supply, delivery, and production line data. This application also serves the production planning application, which itself functions through the management software interface. The technology layer of the architecture consists of a computer device with an operating system and spreadsheet software to realise decision-making and monitoring services. The production machines and, within them, the safety and operational sensors have data flow to the computers and are also associated with production line data.

The baseline architecture shows that there is room for improvement in the functioning of the operations and the data sharing in the customer company aiming to reach the drivers and goals mentioned in the motivation and strategy view of the architecture. There are specific guidelines required for a successful upgrade of the system, which might require the assistance of external parties and upgrading the equipment of the company.

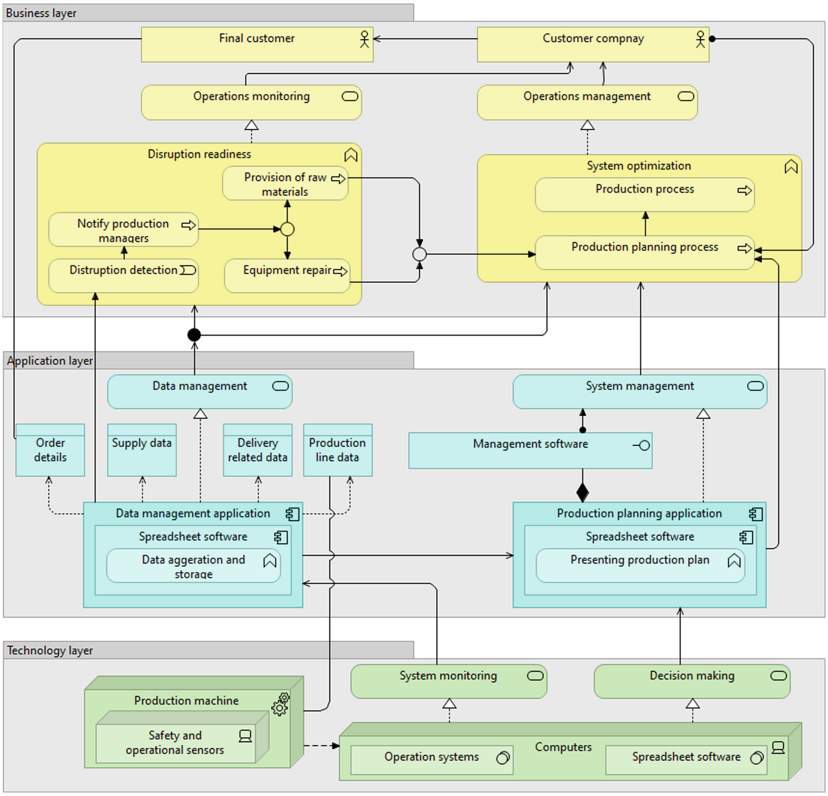

Fig. 3. Baseline architecture

4.2 Target Model

Based on the definitions of RAs, they are generic designs that can be made specific to several cases based on adding further specifications to the models [52]. The vision and logic behind the target architecture design is to create a guide or blueprint for the service-providing and customer companies, assisting them through the collaboration. This initiative leads to offering the factory control and optimisation toolbox by the service provider to the customer companies to reach their drivers and goals mentioned in the motivation and strategy view of the architecture in Fig. 2.

The main changes in the target architecture compared to the baseline are set in motion by designing and adding the dynamic decision-making software to the architecture and adding the service provider as a stakeholder. The dynamic decision-making software will be developed by the service-providing company specifically for each industry with several configurable parameters that help the customer companies of the software to use the services in their company after adjusting it to their conditions. All changes after adding these elements are shown in Fig. 4, and some of the major ones are explored in the following.

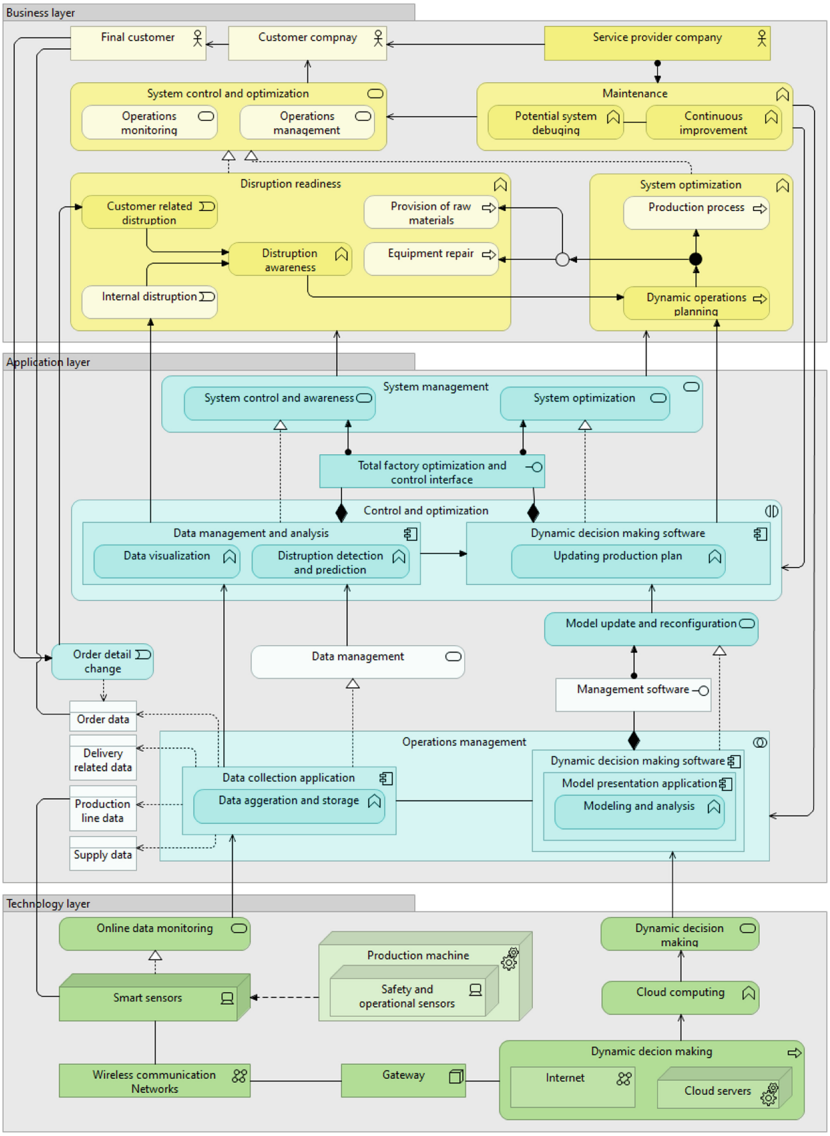

Fig. 4. Target architecture

Adding the service-providing company as a stakeholder will add some functions to the business layer, serving the operation management and monitoring services. The functions assigned to the service-providing company are potential debugging and continuous improvements of their designed application, which serve the system control and optimisation service assigned to the customer company. These connections show that the service-providing company is helping its customer to control and optimise the production processes of the customer company. In the target architecture, the dynamic production planning is triggered by the dynamic decision-making software or the disruption awareness function. The disruption awareness itself is triggered by customer-related or internal disruption events, which will be explored in detail when discussing the application layer.

The structure of the application layer is almost completely changed due to adding the dynamic decision-making software to the architecture. System management service, which consists of system optimisation, and system control and awareness services, is the main component that serves the business layer. This layer also has two added application collaborations with different functions. The first one is operation management collaboration consisting of a data collection application and dynamic decision-making software with data aggregation and storage as well as modelling and analysis functions. The second collaboration is control and optimisation, which consists of data management and analysis and dynamic decision-making software. In this collaboration, the data management and analysis application can trigger the dynamic decision-making software updating the production plan. Also, the data management and analysis application is served by the data collection application accessing the order data. Hence, the changes in order data that can come from the customer in the middle of the production process can change the production plan and require and result in an updated plan that the dynamic decision-making software will present.

The technology services will be changed to online data monitoring and dynamic decision-making to serve the new application layer. The dynamic decision-making service is achieved using cloud computing, which requires cloud servers to transfer data through the internet, and the online data monitoring service requires smart sensors. Also, the internet, gateway, wireless connection networks, and smart sensors are all associated together to serve the technology services. These changes will make data sharing between different production stages possible and improve production planning and disruption readiness. Moreover, these improvements will balance the workload, resulting in an efficient production process. Since the presented architectures only focus on the most common processes and sections of the companies that require production machines for their processing, they are in a generic state that can represent the defined types of companies in different industries.

5 Discussion and Case Study

This section presents a discussion of the research and the case study used to validate it. The motivation and strategy view presented in this study indicate the primal demand for the design of a system that can automate the operations monitoring and management of the production process in manufacturing companies. Since the companies that acquire their production machines from a supplier, such a supplier can also design and offer these management systems to the customers to increase their customer satisfaction, competitive advantage, and profit. However, the design and implementation of the suggested system in different industries might require the extension or simplification of some parts of the presented architectures.

The reference architecture shown in Fig. 4 aims to increase the reliability, flexibility, and efficiency of the performance of the production process of companies that intend to use the introduced service. The introduced service will achieve the mentioned goals by changing the architecture to the target model by incorporating real-time data collection and dynamic decision-making for the production process. The disruption awareness function is also added to the architecture, which leads to real-time changes in the production plan in case of internal or customer-related disruptions detected by the data management and analysis application. Hence, the influence of humans is reduced from the monitoring and decision-making processes resulting in reduced human errors, delays in notifying managers and operators, and the time required for the decision-making process.

In this section, a case study consisting of a service-providing company and one of its customers from the production machine manufacturing industry has been selected to analyse the effects of designing and adding such a system to the current collaboration of these companies. The presented models in the study are designed based on the gathered information from multiple customer companies with different sizes and characteristics, and even located in different countries, however, all in the same industry track. These interviews focused more on the detail of the interactions of the different elements of the business layers of these companies to understand better their current condition and how they would function in the ideal conditions. The other potential case studies of this research can be selected between the companies that require production machines for a part of their production process, while the machines have no integrated system. A system that connects all machines and processes together, collecting real-time data for active planning and disruption management. The limitation of the presented architecture is that there are no specific details regarding what is happening inside the dynamic decision-making software. The reason is that this software would have different characteristics for each specific industry, and adding them to the models would reduce their generic characteristics. This means that even though it has been tried to present models as generic as possible, there could be some cases that would not fit into the category of the mentioned companies, meaning that the models should be modified further to apply to those cases.

To go into more detail on how the different parts of the architecture of the associated companies would be affected when receiving the mentioned services, one specific service-providing company and one of its customers are selected to make the generic models more specific and see the applicability of the presented models. The considered service-providing company has sold several production machines to the customer company of the case study, and now they intend to design a toolbox application with the mentioned functions in the target architecture to be used at the customer company. The customer produces several types of products using its purchased automatic production machines, followed by an interactive human-machine workshop assembling the half-finished products produced as the outflow of the production machines. The first workshop has the characteristics of a flexible or hybrid flow shop, and the second workshop has the characteristics of a job shop workshop. These two workshops should be connected, and the workload between them should be balanced for efficient production.

In more detail, this section focuses on analysing the changes in the business processes of the customer company after using the designed system through the extended business layer views for the baseline and target models. As mentioned, these models are designed in collaboration with experts from the selected production machine manufacturer as the service-providing company and customer companies of their machines. The business

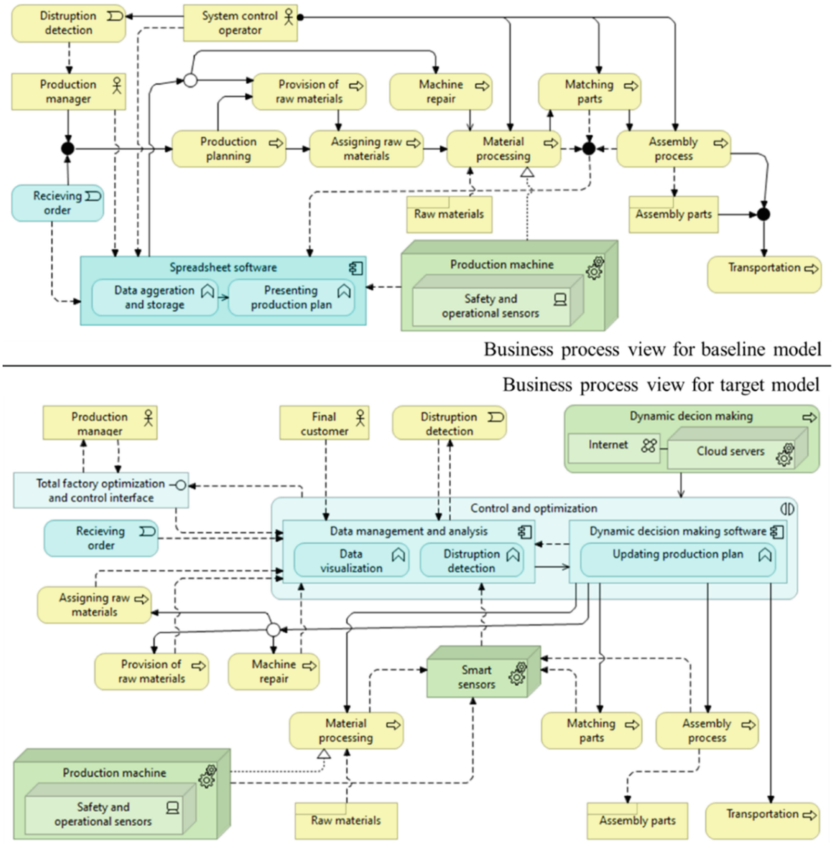

Fig. 5. Business process views

process view for the baseline and target models are presented in the top and bottom parts of Fig. 5, respectively. The main element of the business view for the baseline model is the system control operator, who is assigned to almost all processes for operations monitoring and, subsequently, disruption detection. The production planning in the baseline model is triggered when receiving an order and by the production manager. As presented in the model, the data management system does not influence any processes and functions because it only collects data and only has limited data inflows from different processes. This makes production planning and monitoring relatively slow and vulnerable to human errors.

On the other hand, when looking at the business process view for the target model, it can be seen that the human factors responsible for monitoring and decision-making have been eliminated, and the control and optimisation application is now responsible for all processes. This application interaction consists of data management and analytics, and dynamic decision-making software. The dynamic decision-making software triggers all business processes, and the data management and analysis application receives data from them, making the production process interconnected. Hence, the advantage of developing the structure of the enterprise to the designed architecture is having a central application responsible for real-time data collection and decision-making based on the data. Also, having this central system will increase the flexibility and agility of production planning in case of possible disruptions.

Following the goals of the production machine manufacturer of the selected case study, which has the role of the service-providing company, the control and optimisation software will be developed to be offered to its customer companies. Then the software will be incorporated into the architecture of the customer companies causing its architecture to change and have a business process view similar to the one mentioned at the bottom of Fig. 5. During the development process of the software, the efficiency of the designed toolbox will be validated using a simulation model considering several key performance indicators specified based on the system requirements of the software. This way, the effectiveness of the presented models and the designed toolbox will be translated in terms of key performance indicators that are easier to present to the stakeholders of the suggested collaboration than architectural models and concepts. The final step will be testing the designed toolbox on the customer collaborating in this project and observing the influence of the new toolbox on the company architecture and efficiency of its processes.

6 Conclusion and Future Research

This study presented a reference architecture for a service provision initiative. The architecture helps production machine manufacturers offering an accompanying service to their customers when selling their products, aiming to gain competitive advantages against their rivals and increase customer satisfaction and profit. The proposed target model connects all production steps using real-time data management and analysis, and a dynamic decision-making system. It also reduces the direct interaction of humans with the production process and, subsequently, human errors in disruption and system management.

Further research is needed to go into more detail in analysing the effect of receiving such a service on the operators of the production machines and their reactions to these changes. Moreover, it is required to understand how the real-time data collection process in manual workshops should be done and also the way the changes in the production plan using the dynamic decision-making system should be conveyed to the operators. Moreover, further research is required to go into the technical side of the design and development of the decision-making software and the needed hardware to increase the efficiency of the whole system.

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