SWST – International Society of Wood Science and Technology

Automation Decisions in Manufacturing System Development Projects: The Wood Products Industry Perspective

BIOPRODUCTS BUSINESS

Roaa Salim[1], Kerstin Johansen[2], Agostino Manduchi[3]*, Kristina Säfsten[2]

Abstract

The implementation of automated solutions in manufacturing commonly involves substantial investments in terms of both human and financial resources, and it exposes the firms to the risk of substantial losses if the expected benefits fail to materialize. It is therefore important that decisions related to automated solutions are well supported. The maturity level differs across industry sectors, and the wood products industry is lagging behind in some respects. The purpose of this paper is to explore the potential challenges the wood products industry is facing related to automation decisions when designing manufacturing systems and suggest strategies that can support such decisions, with inspiration from another industrial sector. A multiple case study was conducted, involving a development project carried out in the wood products industry and another in the presumably more mature automotive industry. Automation decisions were studied in the different phases prior to the implementation of the physical manufacturing system. The findings showed both similarities and differences between the development projects. For example, in both development projects, it was decided to reach out to automation suppliers for automation technology acquisition. However, the decision on to which degree to collaborate with the automation suppliers differed. Based on the similarities and differences pointed out, ideas were put forward that might support the wood products industry.

Keywords: Manufacturing system design, development project, manufacturing technology, decision-making, empirical research

1 Introduction

The term "automation" has wide coverage in the manufacturing context. Automation can in principle refer to automated solutions supporting the manufacturing system, such as advanced manufacturing technologies (AMT), robotics, and computerized numerical control machines (CNC). Investments in automated solutions are commonly undertaken to enhance manufacturing performance and are becoming increasingly critical to surviving global competition (Díaz-Reza et al., 2019). Such investments are ideally preceded by a manufacturing system development project, which includes the design and industrialization of a manufacturing system (Bellgran & Säfsten, 2010). A well-designed manufacturing system can greatly benefit the competitive position of a manufacturing company (Bennett, 1986). The design process entails several coordinated decisions related to areas such as automation, organization, product planning & control, facility location, human resources and quality management (Salim, 2021), which should all be based on the company's manufacturing strategy (Hill & Hill, 2009; Jonassen, 2012; Miltenburg, 2005).

The quality of the decision process has a great impact on the results of investments in automated

1 Project Manager, Sogeti - Jönköping, Sweden
2 Department of Industrial Product Development, Production and Design, School of Engineering, Jönköping University, Sweden
3 Jönköping International Business School, Jönköping University, Gjuterigatan 5, Box 1026, 551 11 Jönköping, Sweden
* *Corresponding author.* Email: maag@ju.se

Acknowledgements: Our thanks are due to Anders Johansson for contributing to the design of the empirical studies and the data collection. We also acknowledge the project ProWOOD funded by the Knowledge Foundation and the participating companies.

solutions (Abdel-Kader et al., 2018). Considering the large investments typically required by the implementation of automation projects and the extensive bearing of such projects, it is then critical to provide adequate support to such decisions (Bai & Sarkis, 2013). The literature nevertheless shows that in practice, automation decisions often follow unstructured processes and are often based on ad hoc criteria and on sheer intuition (Lindström & Winroth, 2010).

The wood products industry, defined as the industry that refines wood and transforms it into products such as furniture (Sandberg et al., 2014), as virtually all industry sectors, could benefit from the opportunities offered by automated solutions under the "Industry 4.0" paradigm (Culot et al., 2020; Atzori et al., 2017), possibly also in the context of coordinated efforts such as the *Initiative Industry 4.0* in Germany (Gilchrist, 2016; Kagermann et al., 2013). Initiatives of this type have led to a massive digitalization of production processes and to the diffusion of the technologies related to the (Industrial) Internet of Things, which can affect multiple areas besides automation, such as virtualization, integration, traceability, flexibility, and energy efficiency (Frank et al., 2019).

The pace of the innovative process related to the transition to Industry 4.0 has not been uniform across industry sectors. For example, in the health, automobile, and transportation sectors, both already established firms and start-ups firms have been heavily engaged in innovative activities and production processes (Bongomin et al., 2020; Koh et al., 2019). By contrast, the wood products industry is still characterized as a labor-intensive sector (Ratnasingam et al., 2019), due also to limited experience from manufacturing system development initiatives (Abu et al., 2019). From a manufacturing system perspective, the wood products industry, with its production layouts, also differs substantially from the hardwood sawmill industry, which is more similar to process industries and in which technologically advanced and automated solutions have been used for many years (Sandberg et al., 2014; Young & Winistorfer, 1999).

Studies that provide examples of how other industries have pursued automation investments can greatly help the structural transition of the wood products industry to a more up-to-date model (de Boer et al., 2019; Landscheidt & Kans, 2016). The purpose of the present paper is to explore the potential challenges that the wood products industry is facing in connection with the design of automation manufacturing systems and suggest possible solutions. The paper considers the implementation of two manufacturing automation projects, carried out in the wood products industry and in the automotive industry. The automotive industry is viewed as a valuable source of possible ideas due to the greater experience in the area of automation that the firms in the sector have accumulated in the past few decades, also under the pressure of strong workers unionization and high wage levels (Pavlínek, 2020).

2. Theoretical Background

2.1 Manufacturing System Design

The design of manufacturing systems must be approached from a holistic perspective. The reason is that changes in one part of the manufacturing system can affect other parts (Bauer et al., 2020). This situation substantially increases the complexity of the task of designing manufacturing systems, since it often requires the involvement of multiple functions within the company. Structured and inclusive processes aimed at designing manufacturing systems are thus of primary importance (Bellgran & Säfsten, 2010; Bennett & Forrester, 1993).

In general, manufacturing system design can be presented as a generic stage-gate process, involving several phases and related activities (Bellgran & Säfsten, 2010). Although the accounts of the process of manufacturing system design that can be found in the literature present some differences in their structures and in the terminology used, it is possible to identify some common elements. For example, the literature agrees that the design process includes, among others, a development plan, the statement of the requirements specification, and the generation of a system solution (Andersen et al., 2017). In the case of the wood products industry, the deliveries from the log yard are also an important element of the process (Trzcianowska et al., 2019). Bellgran & Säfsten (2010) present a structure for the design process consisting of five phases: (1) background study, (2) pre-study, (3) design of conceptual manufacturing systems, (4) evaluation of conceptual manufacturing systems, and (5) detailed design of chosen manufacturing system. Figure 1 summarizes some typical

	Typical activities	References
Background study	• Exploration and generation of ideas • Informal discussions • Benchmarking • Product analysis	(Rösiö & Bruch, 2017; Bellgran & Säfsten, 2010; Wu, 1994)
Pre-study	• Formal project initiation • Clarification of the problem and definition of the project objectives • Creation of the project directive • Scoping • Setting objectives • Evaluation of the current manufacturing system • Scenario analysis • Developing requirement specifications	(Rösiö & Bruch, 2017; Bellgran & Säfsten, 2010; Ullrich & Eppinger, 2007; Wu, 1994)
Design of conceptual manufacturing system	• Creation of preliminary manufacturing system concept (generating solutions/ searching) • Choosing system parameters • Determining interrelations • Handling complexity • Risk analysis • Developing concept study report and request for quotation	(Rösiö & Bruch, 2017; Bellgran & Säfsten, 2010; Ullrich & Eppinger, 2007; Wu, 1994)
Evaluation of conceptual manufacturing system	• Determining method of evaluation • Evaluating • Estimating costs	(Bellgran & Säfsten, 2010)
Detailed design of chosen manufacturing system	• Selection of the most suitable manufacturing system concept based on the quotes or the automation suppliers • Automation supplier selection • Risk analysis update • Communicating and establishing support for chosen solution • Refinement of the manufacturing system concept/Refining final design • Planning for realization/implementation	(Rösiö & Bruch, 2017; Bellgran & Säfsten, 2010; Wu, 1994)

Figure 1. Some typical activities in the manufacturing system design process.

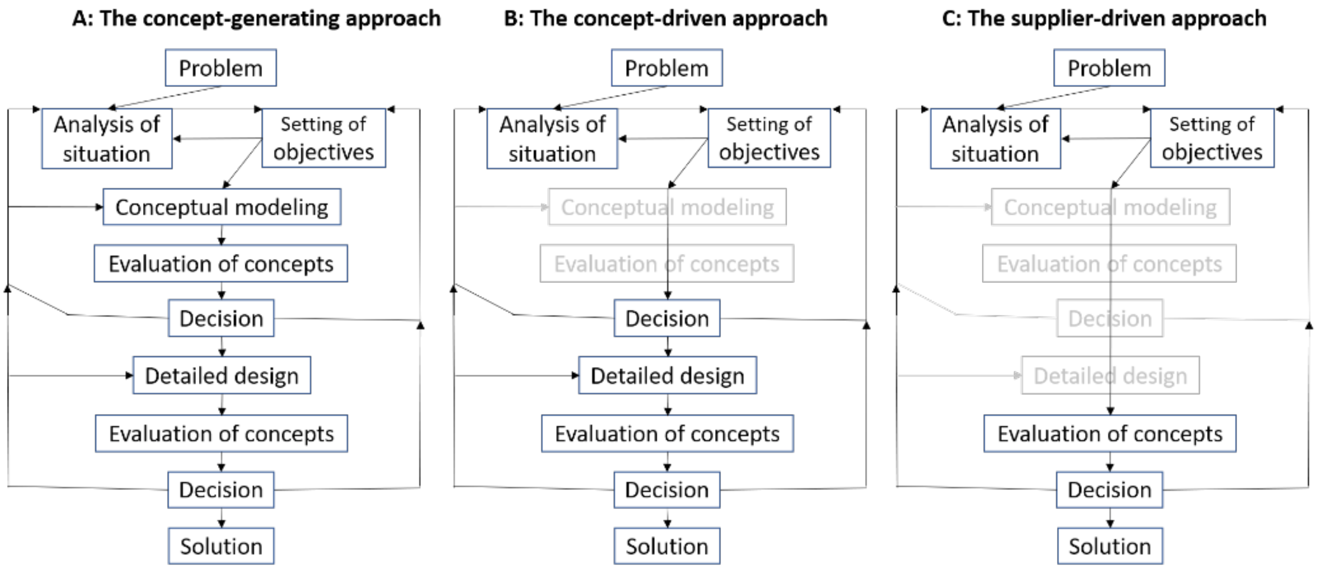

Figure 2. The approaches to manufacturing system design from the manufacturing company's perspective (Säfsten, 2002).

activities in each phase during the design process; each phase is dependent on the completion of the previous one (Bellgran & Säfsten, 2010; Wu, 1994).

The activities in the design process often require the involvement of different human resources, both internal and external to the firm. Three main approaches to manufacturing system design are identified in the literature (Bellgran & Säfsten, 2010): (1) the *concept-generating approach;* (2) the *concept-driven approach;* and (3) the *supplier-driven approach*.

In the concept-generating approach, the manufacturing company is involved, and thus, responsible for all activities in the different phases prescribed in the general manufacturing system design process (Figure 2A). In the concept-driven approach, the manufacturing system design is carried out by the manufacturing company (Figure 2B). However, the design process is driven by external factors such as a pre-existing design or the interests of an actor (Engström et al., 1998). In the supplier-driven approach, part of the design, or possibly most of the design of the manufacturing system, is handed over to automation suppliers (Figure 2C). When the supplier-driven approach is so extensively used that all design activities are outsourced, the manufacturing system design process becomes a "black box" from the perspective of the manufacturing company. In these situations, the manufacturing company should still maintain certain in-house competencies to fully benefit from their interactions with the suppliers (von Haartman & Bengtsson, 2009).

Despite the importance of working in a structured manner and maintaining competence in-house, regardless of the approach to manufacturing system design, manufacturing companies are experiencing limitations when designing manufacturing systems. Previous literature concludes that the design of manufacturing systems commonly is seldom a part of a long-term or strategic approach (Bruch, 2012; Rösiö, 2012). Many companies find it challenging to coordinate the manufacturing system design process and to work in a structured and systematic way (Bruch & Bellgran, 2013; Rösiö & Säfsten, 2013). Trial and error remain the most frequent way of designing manufacturing systems (European Factories of the Future Research Association, 2016). These shortcomings are claimed to be a consequence of the priority given to product design capabilities over manufacturing system design capabilities (Bellgran & Säfsten, 2010; Cochran et al., 2001-2002). In the specific case of automation investments, Frohm (2008) points out that one of the main reasons why these types of investments fail is the lack of clearly defined objectives. The success of the projects—which we understand as the perceived consistency with the goals set for them, as we clarify in Section

3 below—seems to be systematically related to the capability of planning, understanding the needs, and defining the requirements and objectives.

Figures 3 and 4 complement Figure 2 by highlighting the key differences between the concept-generating and the supplier-driven approaches, from the point of view of the present paper. The concept-generating approach makes it possible to carry out an all-encompassing analysis of the company's situation and of its link with the strategic goals, in connection with the exploitation of the opportunities offered by the project. By contrast, in the supplier-driven approach, the reactive mode and the typically limited breadth of the project team can allow the company to make faster decisions, once the decision process is underway; however, it can also hamper the identification of the opportunities offered by the project. Adopting the concept-based approach and eliciting focused offers from multiple suppliers may also allow the company to find a better match between the specific requirements of the project and the features of the machinery and the equipment received (Bellgran & Säfsten, 2010).

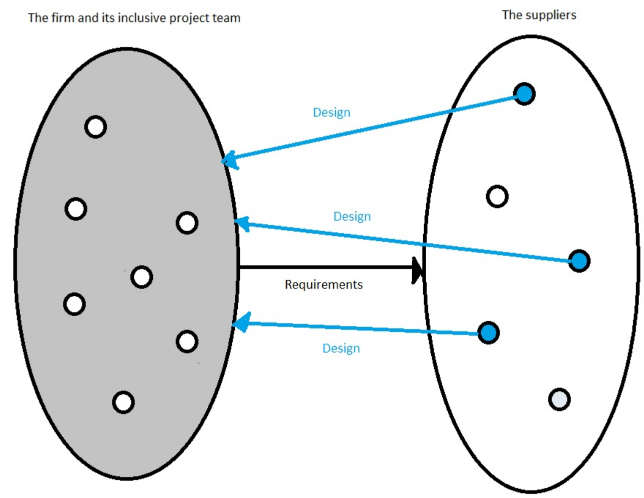

Figure 3. An illustration of the concept-generating approach.

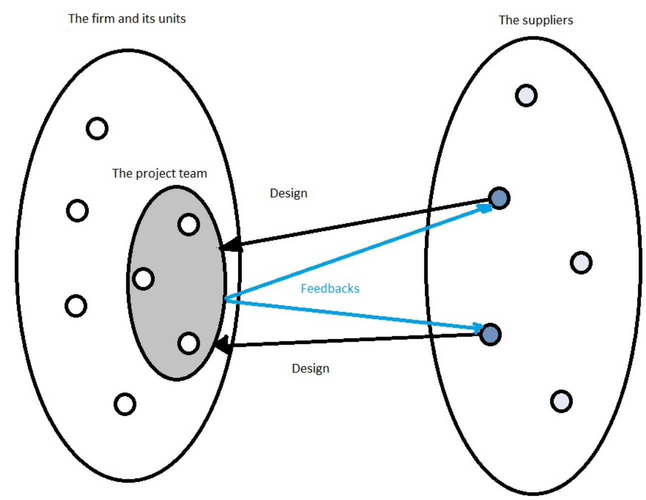

Figure 4. An illustration of the supplier-driven approach.

2.2 Decision-making

Many approaches to practical decision making exist in the literature. Conventionally, there is a distinction between *descriptive* and *normative* models. Descriptive models provide accounts of actual decision processes followed by people and committees. Normative models indicate how the processes should be structured, based on the consistent development of requirements posited as axioms (Lehto et al., 2012; Davis et al., 2005). Models created to provide guidelines that explicitly account for decision-makers' cognitive and informational limitation are sometimes viewed as a distinct category and labeled as *prescriptive* (French et al., 2009).

The cognitive and informational limitations of human decision-makers are especially relevant in the case of complex decisions (Simon, 1955). In situations of this type, decision-makers are likely to resort to formalized routines and/or heuristics, reflecting criteria used to make previous decisions in environments perceived as similar to the one they face on any given occasion (Gilboa et al., 2015). Such routines may incorporate relatively complex inferential and decisional criteria, suitably adapted to the constraints faced by the decision-maker (Gigerenzer et al., 1999). However, they may also incorporate biases that can lead to predictable errors and thus to sub-optimal decisions, even if the account is taken of the decision maker's informational and computational limitations (Kahneman, 2011; Tversky & Kahneman, 1974).

Even if we do not impose strong rationality assumptions, a structured decision process of a normative nature can satisfy minimal requirements related to the informational support available for the decisions and the consistency of the decisions made with the company's overall strategic plans. For example, the process can impose the use of templates and manuals and require the participation of representatives of the different units of a company and thereby guarantee the systematic activity of information-gathering and a more accurate assessment of the opportunities and the risks potentially related to a decision. The prescriptive analysis could thus produce an interactive process in which the conclusions based on a given set of assumptions are explored and refined, and the model itself is adjusted and modified as new evidence emerges (French et al., 2009).

3. Research Methods and Material

To study automation decisions during manufacturing system design, a multiple case study was carried out (Yin, 2018). The unit of analysis was a manufacturing system development project, with automation decisions as an embedded unit of analysis. Two development projects of high strategic value were selected, both aiming at new manufacturing plants.[1] The first development project, Project Wood, was carried out at a large Swedish wood products company (Company Wood). Company Wood consists of several business segments. Project Wood was initiated to create a new business segment, expanding the company's range of products. Its goal was to endow the company with manufacturing solutions designed to add processing value to sawn timber. The second development project, Project Auto, was carried out at a large automotive company (Company Auto). Company Auto is a manufacturer of heavy vehicles for transportation purposes. Project Auto was part of the strategic roadmap, focused on introducing new products and radically new solutions to customers, in line with the developments of customer needs and technology and market dynamics.

3.1 Data Collection

Semi-structured interviews with open-ended questions served as the main tool for data collection, allowing investigations to be based on, but not limited to, predefined questions (Yin, 2018). This procedure provides a reasonable level of flexibility to gain understanding on a complex topic such as decision-making. The interviews started with questions about the development project's purpose and were then narrowed down to questions on the activities and decisions made related to automation, with focus on the challenges of such decisions and how they were supported. In total, 17 face-to-face interviews were carried out, each lasting between 31 minutes and 78 minutes. The interviews were conducted with members of both the steering group and the project group, representing different functions within the company (see Table 1 for an overview).

The same interview guide was used for all respondents. Each interview was recorded and transcribed for analysis. The interviews were carried out by two researchers. Most of the interviews were performed individually, except for one that was carried out at Company Auto with two manufacturing representatives simultaneously.

In addition to the interviews, data was collected through project documentation, such as project description and motivation, meeting protocols, activity time plan, and automation supplier quotations. The information achieved from the documents provided a solid understanding of the context of both projects.

3.2 Data Analysis

A within-case analysis (Merriam, 2009) was carried out first. The procedure suggested by Miles et al. (2019) was used, and the data was then analyzed following the three phases: (1) data reduction, (2) data display, and (3) conclusion-drawing and verification. In the first phase, data reduction, the transcripts and notes from the interviews and the project documentation were reviewed. We only considered types of documents to which we were granted access on equal footing at both companies. Such documents included project descriptions, organizational charts, activity- and timeplans, multiple meeting protocols and requests for quotations. In total, this documentation amounted to approximately 600 pages of written text. The data was then arranged in accordance with the manufacturing system design process prescribed at each company, and the data related to automation decisions were sought.

In the second phase, data display, the data was organized in a matrix, which made it easier to draw conclusions. The third phase was based on the patterns identified in the collected data, as well as relating the findings to the literature. Afterwards, a cross-case analysis (Merriam, 2009) was performed, which enabled the comparison of data between the studied development projects. The data was then arranged in accordance with the manufacturing system design process prescribed at each company,

1 Our confidentiality agreements do not allow us to reveal the identities of the companies.

Table 1. Respondents from Project Wood and Project Auto.

	Steering group	Project group members
Project Wood	Six steering group representatives	Project manager, two marketing and sales representatives, one purchasing representative, one manufacturing representative
Project Auto	One steering group representative	Project manager, one finance and cost control representative, two manufacturing representatives

and the data related to automation decisions were sought. In the second phase, data display, the data was organized in a matrix, which made it easier to draw conclusions. The third phase was based on the patterns identified in the collected data, as well as relating the findings to the literature. Afterwards, a cross-case analysis (Merriam, 2009) was performed, which enabled the comparison of data between the studied development projects.

For the purposes of the present paper, we identify the success of decisional processes with the consonance between the goals and the outcomes of the automation projects, as assessed by the subjects who were interviewed and from whom information was gathered. Special attention was paid to clarifying to what extent the initial goals were revised and adjusted in the light of new information and to the involvement of participants in the projects, which plays a key role in the processes of value co-creation related to innovation (Barile, et al., 2021).

3.3 Research Quality

The validity of the present study was increased by the joint planning and implementation of it, which helps to reduce researcher bias (Denzin, 2009). Two researchers collected and examined the data separately and then compared their perspectives. Validity was further reinforced through triangulation, utilizing various data collection techniques, including interviews and document analysis. All interviews were audio recorded and transcribed, a measure that allows revisits to the empirical data and reduces the risk of misunderstanding (Saunders et al., 2012). Detailed descriptions of both cases were provided to ensure external validity (Yin, 2018). However, one must note that the findings of a qualitative study might not always be replicable, due to different circumstances. Reliability in a qualitative study should rather be based on whether others can see that the findings can be justified by the data collected (Merriam, 2009).

4. Research Findings

In this section, the findings from Project Wood and Project Auto are presented. The description of each project includes the activities carried out, decisions made, challenges encountered, and tactics used to support automation decisions made during manufacturing system design.

4.1 Project Wood

The product to be manufactured was a high-volume product with a relatively high level of customization. To manufacture this product, Company Wood needed to invest in a new manufacturing plant, including automated solutions. During the development process, the management decided to divide Project Wood into parts: Plant 1 and Plant 2. Plant 1 would serve as a pilot plant, aimed to increase the knowledge on the raw material, finished product, and manufacturing system before the company continued with an investment in a full-scale plant (Plant 2). The present study mostly focuses on the design of Plant 1.

In Project Wood, a project model was used to guide the development project. It consisted of three phases prior to the implementation of the physical manufacturing system: (1) pre-study, (2) development and verification, and (3) pre-project, described below.

4.1.1 Project Wood: Pre-study

A small group was initially formed to explore the activities forward. The group's focus was the analysis of market opportunities and the exploration of manufacturing system concepts and solutions, including the identification of suitable automation suppliers. The identification of required automated solutions was challenging due to limited knowledge about the manufacturing system to be developed. The ideas were often based on previous knowledge from existing manufacturing systems within Company Wood, rather on proactive investigation. Similarly, the search for suitable automation suppliers was based on previous knowledge and experience. Moreover, during the pre-study phase, it was decided to hire an external project manager, due to limited resources and lack of in-house competences.

When the external project manager was appointed, a formal project organization was created, with a project manager, a steering group and a small project group including people from manufacturing and marketing. The external members were mostly experts of project management. However, their awareness of the product and manufacturing system to be developed, including the aspects related to automation, was described as generally low. One of the respondents said that "since none of the project organization had previous experiences with either the product or the manufacturing system to be developed, we had to gain knowledge about both as the development project progressed."

To gain information about suitable manufacturing system designs featuring automated solutions, automation suppliers were contacted. Another activity carried out during the pre-study phase was to develop a requirements specification. In general, there was no formal approach to this activity. Multiple respondents observed that important decisions about relevant aspects of the project, such as the location and the size of the building hosting the activities and the product range, had been made by the management team before the project was officially initiated, often to reduce the investment cost. One of the respondents said, "We found out that we were expected to build a new manufacturing system that could handle a fixed volume per year. Each shift should be staffed by a given number of operators. It was not much more information than that…. And we had access to a sum of money… and an existing building that we could use to save money." The decision to use an existing building resulted in constraints on the structure of the manufacturing layout.

The process of requirements specification was described as "very poor"; one respondent noted that "I wish we had better support to achieve more satisfactory requirements specification." The limited size of the project team and the lack of a holistic perspective on automation were also indicated as major challenges by multiple participants.

The main outcome of the pre-study analysis was the decision to purchase a complete manufacturing system concept. Company Wood had made the same decision in previous development projects. In the case at hand, this choice was described as even more obvious, due to the lack of resources and knowledge about the product and manufacturing system to be developed. Reaching out to external sources was perceived as beneficial, since they probably would have relevant experience. It was also highlighted that working with one main automation supplier was preferred, since the involvement of multiple sources could imply challenges regarding compatibility in the manufacturing system. A further decision aimed at reducing the cost of the project was to implement relatively low levels of automation in Plant 1. According to one respondent, this would also provide better opportunities for "learn by doing", possibly also by reducing the risks associated with the process.

4.1.2 Project Wood: Development and Verification

One of the main activities carried out during the development and verification phase was to develop and send the request for quotation to the automation suppliers that the project group had established contact with. The requirements specification developed in the pre-study phase served as input material for the request for quotation. Project Wood fully relied on automation suppliers since there were no development activities carried out in-house. To follow up the development work, the project manager and another project member from manufacturing were in close contact with the automation suppliers. Through this, the project group could observe the ongoing activities and have continuous discussions with the automation suppliers. Another activity carried out at the concept development and verification phase was that the automation suppliers arranged visits to similar manufacturing systems with similar automated solutions for some of the project group members.

During the concept development and verification phase, the automation suppliers presented a complete concept for the new manufacturing system each. In total, two concepts were presented. The project group reviewed and evaluated the proposed concepts. The evaluation was based on which concept met the requirements specified and was within the project's budget. The comparison was based on informal discussions within the project group. One of the respondents said that “We had to choose one of the concepts. It was an easy choice since only one of them was within the project’s budget”. The project group chose what was perceived as the most suitable option and recommended it to the steering group.

The lack of in-house competence about the manufacturing system design, including automated solutions, was emphasized as a challenge in the concept development and verification phase. One respondent said that the “total reliance on automation suppliers together with insufficient requirements specification meant choosing to receive a manufacturing system that was a black box, which we know nothing about and cannot change. How can we then be competitive”? Another respondent added that the automation suppliers would probably offer similar automated solutions for them as they do for their competitors. The respondent referred to this way of working as seeking “copy-paste” solutions which would limit the company’s opportunities to utilize the competitive advantages of the automated solutions implemented. Another challenge emphasized during this phase was that the purchasing function was involved relatively late. The purchasing function was from an external business segment within the company and stated that they had standardized protocols that could have been beneficial to include at earlier phases of the development process. Being involved late meant limited flexibility for change. An additional challenge that was brought forward was the lack of information needed to evaluate the concepts presented. This was described to be a result of insufficient requirements specification and lack of documentation from previous phases in the development process. Moreover, although automated solutions were considered early in the development process, the objectives for automation were not specified. The unclear objectives were stressed as another source of challenge when evaluating the different solutions.

4.1.3 Project Wood: Pre-project

During the pre-project phase, the manufacturing system concept recommended to the steering group was selected. Some respondents mentioned that deciding on the final solution was tough but also easy in a way. It was tough due to the scarce information but easy due to the limited options. The respondents further agreed that the steering group was presented with scarce information about suitable final solutions. When the decision regarding the final solution was made, details regarding the selected manufacturing system concept were finalized together with the selected automation supplier and the planning for realization started.

A further major decision, made by the management at Company Wood, during the pre-project phase was to accelerate the development of Plant 2 before Plant 1 was fully developed and its automation solutions and mechanics were explored in detail. The reason for rushing the process was that a competitor was starting a similar manufacturing plant in Sweden. Since the plans of initiating Plant 2 were accelerated, the project organization expanded at this phase of the development process. Various resources from different functions within Company Wood were involved. Many of them were newly employed specifically to join the development of Plant 2. It was also decided to hire a new project manager for Plant 2. The reason was that the Plant 1 and Plant 2 would run simultaneously and having a project manager for each plant was perceived as more beneficial. This confused some members in the project organization that questioned the aim of Plant 1. The findings from three studied phases prior to the implementation of the physical manufacturing system in Project Wood are displayed in Table 2.

4.2 Project Auto

The product to be manufactured was a high-volume product with a relatively high level of customization. To manufacture this product, Company Auto needed to invest in a new manufacturing plant, including automated solutions. The requirements of such development project were specified in terms of time-horizons within which new products and product concepts should be developed, tested and brought to the market.

In Project Auto, a project model was used consisting of five phases prior to the implementation of the physical manufacturing system: (1) Background Study, (2) Pre-study, (3) Requirements Specification, (4) Quotation and (5) Procurement, described below.

4.2.1 Project Auto: Background Study

Project Auto was initiated at the management level as a consequence of a product development project.

Table 2. Findings from Project Wood.

	Main activities related to automation	Main automation decisions	Challenges related to automation decisions	Tactics used to support automation decisions
Pre-study	• Identify automation suppliers • Gain knowledge about automated manufacturing systems • Contact automation suppliers • Develop requirements specifications	• Divide the development project in two sub-projects • Buy a complete automated manufacturing system • Start with low levels of automation to reduce costs and exploit learning by doing • Use an existing building for the new automated manufacturing system, to reduce costs	• Lack of in-house competence regarding automated solutions • Lack of support for the definition of the requirements • Lack of a holistic perspective on automation due to limited involvement of human resources	• Increase in-house knowledge about automated solution by starting with a pilot plant • Increase in-house knowledge about automated solutions by hiring an external project manager • Secure knowledge about automated solutions through automation suppliers
Development and evaluation	• Elicit offers from automation suppliers • Continuously benchmark and discuss with automation suppliers • Visit related automated manufacturing system setups • Review and evaluate automation suppliers manufacturing system concepts, - Recommend the most suitable automated manufacturing system concept to the steering group		• High reliance on automation suppliers due to lack of specific in-house competence • Late involvement of purchasing unit • Insufficient requirements specification • Lack of documentations from previous phases • Lack of objectives for automated solutions	• Rely on suppliers to increase knowledge about automated solutions
Pre-project	• Decide about the proposed manufacturing system • Finalize details regarding the system • Build the system	• Select the most suitable automation supplier • Start with Plant 2 earlier than planned – with only limited feedbacks from the pilot plant.	• Scarce information	

At the background study phase, the development process was described as informal and included a small number of people involved in exploring ideas and following up the development of ongoing activities. It was described as a source of challenge for supporting automation-related decisions where a holistic perspective is included. A research and development manager at Company Auto was assigned as the main project manager.

During the background study phase, the main effort was placed on activities related to product development. However, manufacturing representatives were assigned to participate early from the start and were assigned to explore innovative ideas outside current manufacturing system set-up with emphasis on cutting-edge automated solutions.

Automation of manufacturing was described to have a central role in Project Auto. At this phase of the development process, it was decided to implement relatively high levels of automation. One respondent said that "our vision was to automate to as high level as we could as far as it still was profitable". The reason for this was the company's strategy on having a manufacturing system that would become world-class within the industry. Since automation had a central role in Project Auto, it was also stressed as important to set clear goals early on, which could be followed up during the development process.

4.2.2 Project Auto: Pre-study

In the pre-study phase, a formal project organization was assigned. The project organization included a steering group; a main project manager; multiple sub-project managers responsible for different areas, including automated solutions; and project group members chosen to represent a wide variety of functions within Company Auto. The involvement of multi-skilled project group members was stressed as important to support decision-making in the development process. Company Auto had established a template used in large development projects to assure the creation of multi-skilled projects teams. The template included a description of the different functions within the company that needed to be involved, to which extent, and in which phase of the development process.

During the pre-study phase, different ideas on manufacturing system concepts, including automated solutions, were explored. Activities such as analyzing current manufacturing solutions and future needs were carried out. Moreover, technology profiling was performed to identify the type of automated solutions required. A template established at Company Auto was used to support technology profiling. The template included the identification of the type and level of automation needed, the usage mode, etc. Since product and manufacturing system development activities were carried out in parallel, continuous analysis of the impact the product changes could have on the manufacturing system were performed.

Moreover, some decisions were made during the pre-study phase. One of the main decisions related to automation concerned what to buy and what to make in-house. Another decision made was that all automated solutions implemented in the new manufacturing system must be known to the company. Therefore, it was decided that all new automated solutions would be installed in advance in an existing manufacturing system before Project Auto was finished so the operators had access to training. Two main challenges of making decisions related to automation were pointed out. The first one was that various activities related to product and manufacturing system development were carried out simultaneously. Thus, various decisions were interdependent and needed to be compatible. The second challenge of making decisions, including automation decisions, was the coordination between the different internal and external sources that were involved in the development project.

4.2.3 Project Auto: Requirements Specification

In the requirements specification phase, the main activity related to automation was the development of a requirements specification. The requirements specification was developed based on the input from the different activities that were carried out previously, as well as a handbook that, for example, included different standards relevant for the manufacturing system. The handbook used was developed by Company Auto to support large development projects. The aim of the requirements specification was to serve as input material for the request for quotation that would be presented to the automation suppliers.

4.2.4 Project Auto: Quotation

During the quotation phase, the focus was placed on creating a suitable manufacturing system concept, including automated solutions. Some development activities were carried out in-house with a focus on customized solutions, while others were developed in collaboration with automation suppliers. To secure external skills in automated solutions, Company Auto chose to invite automation suppliers simultaneously to a workshop for open negotiation. Based on the requirements specification, a request for quotation was developed and presented to the automation suppliers. The automation suppliers were also presented with other necessary information, including a handbook on manufacturing standards that need to be followed. In total, eight automation suppliers were selected to proceed in the development project. Due to the large extent of the development project, the automation suppliers were encouraged to collaborate. The selected automation suppliers worked in pairs and presented, in total, four different manufacturing system concepts. The main challenge related to automation decisions at this phase was described in terms of coordination between the different internal and external resources involved in the development project.

The key activity carried out when manufacturing system concepts were presented was evaluation of the concepts. The evaluation was performed by the project manager together with the project group members who reviewed the proposals. To evaluate the proposed manufacturing system concepts, risk analysis on each concept, including automated solutions proposed, was performed separately. In addition, documentation from earlier phases of the development process was used as the basis for evaluation to review how well the concepts fulfilled the objectives and scope of the development project. The different manufacturing system concepts were, among others, viewed in terms of how well they fulfilled the requirements specification, including the objectives set for the manufacturing system, the goals set for the automated solutions, and the project's budget. The different concepts were presented to the steering group, and the most suitable one was recommended by the project group.

4.2.5 Project Auto: Procurement

The procurement phase in Project Auto was similar to Project Wood. In both development projects, the most suitable manufacturing system concept recommended to the steering group was selected. The steering group trusted that the project group was the most knowledgeable regarding the choice of the final solution. However, one aspect that was highlighted as critical was the project budget that had to be taken into consideration. When the decision regarding the final manufacturing system concept was made, details regarding the selected concept were finalized, together with the automation supplier, and the planning for realization started.

At the end of the procurement phase, checklists were developed by the project group and shared with the automation suppliers to be used during the implementation phase as a tool to follow up on how well the agreements are fulfilled.

5. Discussion

The findings show that although the project models used in the development projects studied did differ, they included some shared phases, in accordance with previous literature on manufacturing system design (Bellgran & Säfsten, 2010): background study, pre-study, design of the conceptual manufacturing system, evaluation of the conceptual manufacturing system, and detailed design of the chosen manufacturing system. Comparing the key activities performed in the different phases in Project Wood and Project Auto to the literature presented in Figure 1, similarities can be found. A comparison between a general development process presented in literature and the project models used in Company Wood and Company Auto is provided in Figure 5.

In the following sections, Project Wood and Project Auto are compared, in terms of the challenges and tactics used, for automation-related decisions in the five different phases of manufacturing system design presented in the literature.

5.1 Background Study

In both development projects, the background study phase was rather informal, and the project organization only included a few people, mostly from the management level. The consequence of this was described in terms of the lack of a holistic perspective when automation decisions were made. The main aspects to which attention should be paid are human resources and the skills available (Kumar et al., 2017), the organizational culture (Mellor et al., 2014), process compatibility (Scannell et al., 2012), and the relationships with the supply partners (Caimon, 2009).

To guarantee a holistic perspective, a multi-skilled project group was created during the pre-study phase in Project Auto, based on an established template used for a large development project in the company. This could have been useful in Project Wood to identify the late involvement of the purchasing function as a challenge for automation related decisions. A complementary strategy tool that can be used to pursue the same goal is the definition of structured guidelines on what needs to be considered in the different phases of the manufacturing-system design process when different decisions, including automation decisions, are being made (Bruch, 2012).

Another challenge identified in Project Wood throughout the different phases of manufacturing-system design process was the lack of in-house competence regarding automated solutions. This challenge is described as prevalent in the wood products industry by previous literature (Sowlati & Vahid, 2006). The wood products industry is characterized by a low education level in the workforce (Ratnasingam, 2015; Teischinger, 2010). Companies operating in the industry are struggling to meet their growth prospects (Kozak, 2005), and skills and knowledge are emphasized as a big impediment (DeLong et al., 2007). However, lack of in-house competence is not specific to the wood products industry but is also addressed in different industrial sectors in relation to investments in automated solutions in manufacturing (Nujen et al., 2018).

Improving on this state of affairs requires investments in qualified human resources. In Project Wood, a step in this direction was made by hiring an external project manager with experience in manufacturing systems and automated solutions. In Project Auto, a

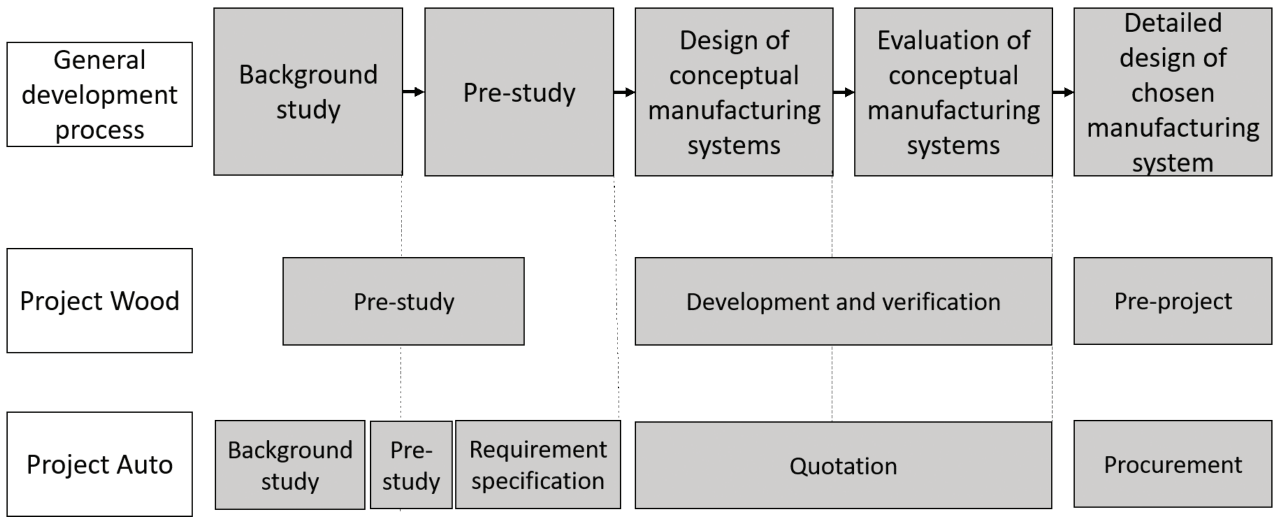

Figure 5. Overview of the development processes studied.

project manager was assigned to be responsible specifically for automated solutions. An additional way to deal with the lack of in-house competence was by securing knowledge through automation suppliers, which was done in both development projects. This is a common approach utilized in manufacturing-system development projects that can be seen in various industrial sectors (Ahlskog et al., 2015). The findings further show that in both development projects, it was decided to strengthen the competence by testing all automated solutions that were new to the company in advance of the implementation of the new manufacturing system. The aim was to learn more about automated solutions and enable training for operators prior to the change. In the wood products industry, training is emphasized as essential to support the implementation of new automated solutions (Wiedenbeck & Parsons, 2010; Pirraglia et al., 2009). Previous literature, including from various industries, also indicates that training is critical in order to utilize the full benefits of investments in automation of manufacturing (Kumar et al., 2017).

5.2 Pre-study

A major challenge identified in Project Wood during the pre-study phase was the specification of the requirements for the solutions, which represents a critical part of the process (Bruch et al., 2009; Granlund & Friedler, 2012). This might result from poor in-house competence regarding automated solutions in the wood products industry (Salim et al., 2020). The findings of this paper show a need to support the development of requirements specification, which can be done through investing in human resources. The development of requirements specification could be supported through working in a structured manner, such as in Project Auto, by providing, for example, handbooks and templates supporting the decision-makers.

5.3 Concept Development

In the concept development phase, automation suppliers were reached for automation technology acquisition in both development projects. Involving automation suppliers in manufacturing system design is common (Reichstein & Salter, 2006). The difference observed in the studied development projects was the extent to which the automation suppliers were involved. Lee et al. (2009) divide automation technology acquisition into three broad categories: make, cooperate, and buy. In Project Wood, a full reliance on automation suppliers was observed, and the purchase of a complete manufacturing system concept, including automated solutions, was sought. The disadvantage of companies relying heavily on R&D outsourcing is that it might hurt their innovation performance, since they will acquire commercially available automated solutions that are probably less unique and thus more prone to imitation by competitors (Grimpe & Kaiser, 2010). This concern was also expressed by a project group member in Project Wood.

In Project Auto, the choice was to cooperate, which is defined as “various forms of cooperation with another firm with or without equity involvement such as joint venture, joint R&D and alliance” (Lee et al., 2009). Various automation suppliers were invited to the workshop for open negotiation. Another tactic used was to encourage collaboration between automation suppliers, which aimed to increase innovation. The automation suppliers were also provided a handbook developed by Company Auto to follow up on standards for the manufacturing system, including automated solutions to be developed.

By contrast, in Project Wood, working with multiple automation suppliers was avoided. This was explained to be due to problems regarding the compatibility of the equipment, as well as challenges with manufacturing certifications, which had to essentially be taken care of by the company. The disadvantage of involving few automation suppliers is that some relevant external knowledge might be lost. Kang et al. (2015) state that by accessing a broader spectrum of external automation technology providers, firms enhance the possibility of gaining relevant technological knowledge. However, there is a point at which the breadth becomes disadvantageous. To avoid full reliance on automation suppliers, the findings show a need for investment in in-house competence and, instead of relying on few external resources, to widen the search for external knowledge.

5.4 Concept Evaluation

In Project Wood, the evaluation of the proposed manufacturing system concepts, including automated solutions, by the automation suppliers was described as a source of challenge in decision-making, due to lack of information. The lack of information was described as a result of poor requirements specification, lack of documentation from previous phases, and lack of objectives for automated solutions.

Setting objectives early in the development project might be critical for the evaluation of final solutions, including automated solutions (Frohm, 2008). More structured process routines would also be beneficial. Through structured decision-making, a discipline on the decision-makers can effectively be imposed, for example, via templates and manuals. This is seen in Project Auto, where different activities were carried out, and templates and handbooks were used to support automation-related decisions during the evaluation process.

5.5 Detailed Design

When choosing the final solution in Project Wood, the focus was shifted towards selecting the most suitable automation supplier. In Project Auto, on the other hand, the choice was directed towards selecting the most suitable manufacturing system concept. This is in line with prior research showing that companies selecting supplier-driven approaches tend to evaluate automation suppliers rather than proposed manufacturing system concepts (Bellgran & Säfsten, 2010). Another observed difference was that in Project Auto, the planning for the realization of the physical manufacturing system included the use of checklists to assure that the agreements made with automation suppliers during the manufacturing system design are fulfilled during the implementation phase. This is another example of where a systematic approach to support decision-making was not sought for in Project Wood.

Last, in both development projects, it was decided that all new automated solutions to the company would be tested in advance. This was later deprioritized in Project Wood to speed up the time plan.

5.6 Decisional Structures

Through the analysis of the development projects, several specific issues related to the automation decision process followed by Project Wood are identified. From a broader point of view, it appears that the effectiveness of future automation investments would benefit from the implementation of systematic routines. The development of the organizational skills and the competencies required by the routines would require time, and the full benefits resulting from the organizational innovations should not be expected to immediately manifest themselves. However, as was argued in Section 2, a systematic process involving the different functions of the organization could produce favorable effects on the decisions, at the very least by providing an adequate informational basis for the decisions (French et al., 2009).

Collecting information from different units and assessing the opportunities that automation pres-

Table 3. Summarizing identified challenges related to project phases, with tactics to support automation decisions in the wood products industry

Summarizing project phases	Challenges related to automation decisions in wood manufacturing	Tactics to support automation decisions
Background study	• Lack of holistic perspective • Late involvement of key resources, such as purchasing • Lack of in-house competences	• Organize a multi-skilled project team • Develop a template for development projects • Develop relationships with automation suppliers • Hire an external project manager • Test all automation solutions before implementing these in the manufacturing system as a training program for the operators
Pre-study	• Development of the requirement specification	• Invest in human resources • Develop and provide handbooks and templates supporting decision-making
Design of conceptual manufacturing systems	• Risk to loosen knowledge if to high degree of external suppliers • The degree of involvement of an automation supplier in the development phase • The timing about when to involve an automation supplier • The ownership and control of innovations • Compatibility between different equipment and machines	• Decide what to make internally • Decide what to cooperate with a supplier about • Decide what to buy as a turnkey solution • Encouragement to collaboration between automation suppliers • Invest in in-house competence
Evaluation of conceptual manufacturing systems	• Importance of proper requirement specification • Defined objectives for automated solutions	• Develop and use templates and handbooks
Detailed design of chosen manufacturing system	• The manufacturing system concept in combination with the right level of automation	• Secure to evaluate the manufacturing system and not the automation supplier • Develop and use a checklist for the evaluation • Test the automated solutions in advance

ents for them—for example, because such activities are necessary to produce manuals of the type used within Project Auto—would help the company to formulate objectives and technical specifications for the automation investments. The company could thus avoid the extensive reliance on the automation suppliers, which was indicated as unfavorable. Decisions organically linked to the overall strategic plan would also allow the company to follow a more proactive strategy (Kahneman et al., 2013). The company could then limit the risk of being forced to craft decisions that are essentially conceived as responses to the competitors' decisions, as was the case for the automation decision that we analyzed, thereby fostering its competitive position.

Table 3 summarizes measures that companies in the wood product industry could adopt to support automation decisions.

6. Conclusions and Implications

This paper has identified some challenges related to automation decisions in the wood products industry. Such challenges are typically related to decision-making regarding automation and are connected to the lack of objectives for automated solutions, lack of competence regarding automated solutions, and lack of structured approaches in the development process. As we noted in Section 5, our findings are related to the findings of related studies in the extant literature, both in the wood industry and in manufacturing in general. For example, the importance of well-structured interactions with suppliers are highlighted in Ahlskog et al. (2015) and Reichstein & Salter (2006), whereas Pirraglia et al., (2009) and Wiedenbeck & Parsons (2010) emphasize the importance of human resources and competence development.

The measures discussed in the paper could help the firms in the wood products industry to tackle these challenges. The direct implications of potential relevance for the managers, staff and specialists involved in automation decisions can be summarized as follows.

(1) Investment in automated solutions in manufacturing should not be focused only on benefits of more immediate relevance. Rather, there should be clear strategic objectives for the automated solutions (Frohm, 2008; Thomas et al., 2008), and automation-related decisions should be closely interconnected with these objectives. An approach of this type would presumably have allowed Company Wood to take a proactive stance in the automation investments. In general, it would also be helpful to better clarify the goals of the investment project, which were found to be quite opaque by the project participants; this conclusion is in line with the conclusions drawn by Trzcianowska et al. (2019) relative to log-yard design and operations.

(2) Investments in greater in-house expertise related to automated solutions could be helpful to deal with future investment in Company Wood. On a related note, the impact of the automation investment should be considered on a company-wide basis. Automation investments can have mostly favorable repercussions on most, if not all the functions involved in the company's productive activities, from marketing to inventory management; such effects are likely to be ignored if the company exclusively focuses on the effects directly related to physical manufacturing. This is supported by a survey by Thomas et al. (2008) that concludes that limitation from financial and human resources could be an obstacle for the adoption of technologically complex solutions, and that top management can have unrealistic expectations about the ease with which advanced solutions can be implemented. An essential feature that a decision process satisfying such requirements must possess is the involvement of human resources from all functional units in the project group, allowing them to assess the broad impact and the benefits of the investment.

(3) Well-crafted, systematic protocols and routines should be adopted to improve the structure of the decisional processes related to automated solutions. For example, the company could adopt handbooks and templates aiming to guide and to support the decision-makers' effort to gather relevant information before making automation-related decisions. Firms can use a design approach for technology implementation (Thomas et al., 2008) to support their endeavor to automate their manufacturing systems and to realize potentially large flexibility gains and cost reductions.

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