JÖNKÖPING UNIVERSITY
School of Engineering

Doctoral Thesis

Exploring the Content and Process of Automation Decisions in Manufacturing System Development Projects

– A Study in the Swedish Wood Products Industry

Roaa Salim

Jönköping University
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Abstract

The wood industry has great potential to support the development of a more sustainable future based on a circular economy. For Sweden to be able to maintain its competitive position as a leading wood industry nation, products with increased added value are needed. To realize this development, new and efficient automated solutions supporting the manufacturing systems in place in the industry are essential. However, although automation of manufacturing can result in competitive advantages, this is far from always being the case. A number of researchers have convincingly argued that investments in automation of manufacturing are more likely to succeed if they are the expression of well-grounded decisions made during the design of a manufacturing system. It is further argued that such decisions need to be linked to a company's manufacturing strategy. And yet despite this, automation decisions are often made ad hoc and based on gut feelings.

The essential purpose of this thesis therefore is to support informed automation decisions in the context of manufacturing system development projects carried out in the wood products industry. To fulfill the purpose, multiple research studies have been conducted including literature reviews and case study method.

This thesis contributes with increased knowledge on the content and process of automation decisions in manufacturing system development projects conducted in the wood products industry. Close study of automation decisions made during manufacturing system design from a manufacturing strategy perspective has produced a set of guiding suggestions. These include the identification of aspects that need consideration when automation decisions are being made during the design of manufacturing systems. Furthermore, through studying the process leading to automation decisions during manufacturing system design, potential pitfalls for the wood products industry are exemplified and tactics used to support decision-making related to automation are suggested. Last, this thesis extends the current understanding about manufacturing systems in the wood products industry by presenting the drivers and challenges for automation of manufacturing.

Keywords: Wood Industry; Manufacturing System Design; Manufacturing Technology; Decision-making; Development Projects

Sammanfattning

Träindustrin har stor potential att stödja utvecklingen av en mer hållbar framtid baserad på en cirkulär ekonomi. För att Sverige ska kunna behålla sin konkurrensposition som en ledande träindustrination krävs produkter med ökat mervärde. För att förverkliga denna utveckling är nya och effektiva automationslösningar som stödjer de produktionssystem som finns i branschen nödvändiga. Men även om automatisering av produktion kan leda till konkurrensfördelar är det långt ifrån att alltid vara fallet. Forskare har hävdat att investeringar i automation är mer benägna att lyckas om de är baserade på välgrundade beslut som tagits under utformningen av produktionssystem. Det hävdas vidare att sådana beslut måste kopplas till ett företags produktionsstrategi. Trots detta fattas automationsbeslut ofta ad hoc och baseras på magkänslor.

Syftet med denna avhandling är därför att stödja informerade automationsbeslut i utvecklingsprojekt för produktionssystem som genomförs inom trämanufaktursindustrin. För att uppnå syftet har flera forskningsstudier genomförts inklusive litteraturgranskningar och fallstudiemetod.

Denna avhandling bidrar med ökad kunskap om innehållet och processen för automationsbeslut i utvecklingsprojekt för produktionssystem inom trämanufaktursindustrin. Studier om automationsbeslut som tagits under utformningen av produktionssystems ur ett produktionsstrategiskt perspektiv har producerat en uppsättning vägledande förslag. Dessa inkluderar identifiering av aspekter som bör beaktas när automationsbeslut fattas. Vidare, genom att studera processen som leder till automationsbeslut under utformningen av produktionssystem, exemplifieras potentiella fallgropar för trämanufaktursindustrin och olika taktiker som kan användas för att stödja beslutsfattande relaterat till automation föreslås. Slutligen utvidgar denna avhandling den nuvarande förståelsen om produktionssystem inom trämanufaktursindustrin genom att presentera drivkrafterna och utmaningarna för automatisering av produktionen.

Nyckelord: Träindustri; Utformning av produktionssystem; Produktionsteknik; Beslutsfattande; Utvecklingsprojekt

Acknowledgement

Here is where it ends! What a journey it has been, filled with joyful moments, new knowledge and adventures but also mental exhaustion and lots of doubts. Although pursuing a doctoral study might feel lonely at times, I have had some wonderful people along the way: I would like to direct my deepest gratitude to them. Kristina Säfsten, without your engagement and encouragement, this thesis would not have been possible. Jimmy Johansson, Agostino Manduchi and Mats Winroth: thank you for guiding me whenever I needed help through this journey. Tomas Bengtsson, Helena Tuvendal, Roger Johansson and Håkan Göransson – I could not have wished for better mentors!

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Last, to the people that matter the most – we did it! Mom and dad, this accomplishment is dedicated to you. Thank you for always believing in me and telling me that I can do whatever I put my mind to. To Hussein, thank you for being the goofy, intelligent younger brother that is always one phone call away. To the love of my life and husband Patrik, thank you for every day showing me the meaning behind the words patience, love and support. I would of course never end this without mentioning my sweetheart Snoffsan. Your purrs and cuddles have been essential for my well-being.

Roaa Salim
Jönköping, 2021-03-12

Appended papers

Paper I

Salim R., Säfsten K., and Winroth M. (2015). Current situation analysis: Manufacturing challenges in the wood products industry. Proceedings of the 23rd International Conference on Production Research (ICPR), Manila, Philippines, 2-5 August 2015.

Contribution: Salim, Säfsten and Winroth planned the empirical study, which was carried out by Salim. Salim analyzed the data and wrote the paper. Säfsten and Winroth reviewed the paper and provided comments for improvements. Salim was the corresponding author and presented the paper.

Paper II

Salim R., Johansson J. (2016). The influence of the raw material on the wood products manufacturing. Procedia CIRP, Vol. 57, pp. 764-768.

Contribution: Salim planned and carried out the empirical study. Salim analyzed the data and wrote the paper. Johansson reviewed the paper and provided comments for improvements. Salim was the corresponding author and presented the paper.

Paper III

Salim R. (2018). Drivers and challenges for automation of manufacturing: A multiple case study in the Swedish wood products industry. Proceedings of the 25th Annual European Operations Management Association (EurOMA) Conference, Budapest, Hungary, 24-26 June 2018.

Contribution: Salim initiated and wrote the paper. The empirical data underlying Paper III was collected by Salim and co-authors from a previous publication. Salim reanalyzed the collected data for this paper and was the corresponding author that presented the paper.

Paper IV

Salim R., Säfsten K., Winroth M., Johansson J. (2021). Automation decisions from a manufacturing strategy perspective – A systematic literature review. Manuscript submitted for review.

Contribution: Salim, Säfsten and Winroth planned the theoretical study, which was carried out by Salim. Salim analyzed the data and wrote the paper. Säfsten, Winroth and Johansson reviewed the paper and provided comments for improvements.

Paper V

Salim R. and Johansson J. (2018). Automation decisions in investment projects: A study in the Swedish wood products industry. Procedia Manufacturing, Vol. 25, pp. 255-262.

Contribution: Salim planned and carried out the empirical study and analyzed the data. Salim and Johansson wrote the paper. Salim was the corresponding author and presented the paper at the 8th Swedish Production Symposium (SPS) Conference in Stockholm, Sweden, 2018.

Paper VI

Salim R., Manduchi A., Johansson A. (2020). Investment decisions on automation of manufacturing in the wood products industry: A case study. Bioproducts Business, Vol. 5 No. 1, pp. 1-12.

Contribution: Salim and Johansson planned and carried out the empirical study. Salim analyzed the data. Salim and Manduchi wrote the paper together.

Paper VII

Salim R., Johansson A., Johansen K., Manduchi A., Säfsten K. (2021). Supporting automation decisions in manufacturing system development projects – The wood products industry perspective. Manuscript submitted for review.

Contribution: Salim and Johansson planned and carried out the empirical study. Salim analyzed the data and wrote the paper together with Johansen, Manduchi and Säfsten.

Additional publications

Journal article

Johansson A., Gustavsson L., Salim R. (2021). Multiple stakeholder value creation: Case studies of innovative production system developments. Manuscript submitted for review.

Conference papers

Salim R., Mapulanga M., Saladi P., Karltun A. (2016). Automation in the wood products industry: challenges and opportunities. Proceedings of the 7th European Operations Management Association (EurOMA) conference, Lund, Sweden, 25-27 October 2016.

Salim R., Andersson O., Schneider C., Winroth M., Säfsten K. (2016). Levels of automation in the wood products industry: A case study. Proceedings of the 23rd Swedish Production Symposium (SPS) conference, Trondheim, Norway, 17-22 June 2016.

Licentiate thesis

Salim R. (2017). Exploring aspects of automation decisions – A study in the Swedish wood products industry. Licentiate Thesis, Jönköping University, Sweden.

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1. Introduction

This chapter starts with a description of the background to the research. It addresses the importance of the wood products industry and the main challenges the industry is facing. Then, the research problem is outlined, with a focus on automation decisions in manufacturing system development projects. The chapter continues with explanations of the thesis's purpose and a breakdown of the research questions, along with descriptions of the scope and delimitations. Last, an outline of the thesis is provided.

1.1 Background

The wood industry taken as a whole is a broad sector that comprises various industries including pulp and paper industry, board industry, energy conversion and sawmills (Sandberg, et al., 2014). The wood products industry is defined as that part of the wood industry that further refines wood as it passes through sawmills to transform it into desired products (Sandberg, et al., 2014). This is usually achieved by additional manufacturing steps, such as surfacing, drying and assembling. The wood products industry includes several business areas, such as home building, furniture-making, packaging, millwork and floors, doors and windows, cabinetry and moldings, to name just some (Sandberg, et al., 2014; Bumgardner, et al., 2005; Kozak & Maness, 2003).

As a whole, the wood industry greatly impacts the competitiveness of European industry. According to the European Confederation of Wood Industry (2009), the industry helps drive the global economy and provides a number of welfare benefits in Europe. Furthermore, the wood industry has great potential to support the development of a more sustainable future with a circular economy (Klarić, et al., 2016). Wood is a material that has several applications, and one of its advantages is that it has a low impact on the environment in comparison to other materials such as cement (Hill & Dibdiakova, 2016). It is possible to reuse and recycle it, and above all, wood can be used as a carbon-neutral source of energy (SwedishWood, 2020). In addition, wood can be used to replace materials of fossil origin, which gives the wood industry the opportunity to become the biggest future producer of green electricity and biofuels in Europe. Wood is also the most commonly used renewable construction material in the world, and furthermore it has increased its market share tremendously during recent years (Forest Platform, 2018). From a life-cycle perspective, there are climate benefits to using wood in construction as it – among other benefits – shortens construction time and results in lower emissions (Regeringskansliet, 2018).

In Sweden, 70% of land is covered by forests, making the wood industry of great societal importance with a share of 9–12% of total employment, turnover and value-adding activities (Forestindustries, 2016). Approximately two-thirds of the timber volume annually produced at Swedish sawmills is directly exported without any further refinement (Forestindustries , 2019). This is worrying since the domestic refinement of wood strengthens the overall wood industry's growth and competitiveness, creates more employment opportunities and drives the development of sustainable growth, as well as stimulating a growing circular and bio-based economy (Regeringskansliet, 2018). Further, an increased degree of refinement in the wood industry provides healthier profit margins, making the wood products industry even more important for Sweden's general prosperity (Forestindustries, 2020). Without strategic investments in further refinement of wood products, the wood industry's contribution to the country's economy risks a gradual decline. For Sweden to maintain its leading position among nations with significant wood industries, new products with increased added value are needed (NRA Sweden, 2012). New and efficient automated solutions supporting manufacturing systems are widely stressed as essential for this development to proceed (Spetic, et al., 2016; Agenda Trä, 2013; NRA Sweden, 2012).

Automation of manufacturing is generally emphasized as a key step in the pursuit of improved productivity (Winroth, et al., 2007). Productivity improvements aimed at preserving the economic viability of the wood products industry are regarded as a high priority by the companies operating in the sector (Ratnasingam, et al., 2020). This is so since wood products companies in high-wage economies are facing several challenges due to increased global competition, both from the use of alternative materials and from competitors in low-wage economies (NRA Sweden, 2012). Some wood products companies still use essentially manual manufacturing processes (Ratnasingam, et al., 2018; Sertić, et al., 2018). This has challenged the industry from an array of angles, such as work environment conditions, productivity and manufacturing costs (Eliasson, 2014; Karltun, 2007). However, investments in automation of manufacturing can be a challenge since it is often hampered by, among other things, the lack of expertise and inadequate technical knowledge of the labor force (Ratnasingam, 2015).

1.2 Problem area

In a manufacturing context, the term *automation* is broad and covers the use of several technologies supporting manufacturing systems, such as computer-aided manufacturing (CAM), robotics, flexible manufacturing system (FMS) and computerized numerical control machine (CNC), allowing companies to make a more efficient use of both cognitive and physical human labor (Groover, 2015; Sheridan, 2002).

Investments in automation of manufacturing are commonly undertaken to enhance performance in an attempt to stay competitive in the global market (Machuca, et al., 2011). Such investments are often made in connection to work related to manufacturing system development. Manufacturing system development comprises the design and industrialization of a manufacturing system (Bellgran & Säfsten, 2010). Whereas manufacturing system design focuses on the planning of a manufacturing system, industrialization deals with the realization of the physical manufacturing system (Bellgran & Säfsten, 2010). The activities related to manufacturing system development can be described as a process, one that is commonly carried out in the context of a product development project but which could also be carried out as stand-alone manufacturing system development projects (Bellgran & Säfsten, 2010). Within manufacturing system development literature, the design of manufacturing systems is stressed as especially interesting, the reason being that the ability to create competitive manufacturing systems is achieved through the design process (Bennett, 1986). The manufacturing system design entails essentially a number of decisions that must be made, including automation decisions, to achieve a stated target (Jonassen, 2012)

Automation decisions are believed to have a crucial impact on the results achieved from investments in automation of manufacturing (Abdel-Kader, et al., 2018). While automation of manufacturing can result in substantial benefits for some companies, others fail to achieve expected outcomes (Kumar, et al., 2017; Almannai, et al., 2008). The literature states that investments in automation of manufacturing tend to succeed if they are the expression of decisions that are well-grounded and aligned with a clear manufacturing strategy (Garrido-Vega, et al., 2015; Liu, 2013; Jiménez, et al., 2011).

A manufacturing strategy defines the objectives and long-term direction of a firm (Akarte, 2018). Manufacturing strategy is often divided into content and process (Dangayach & Deshmukh , 2001; Hayes & Wheelwright, 1984). The literature on the former discusses various competitive priorities and decision areas supporting the achievement of competitive advantages in a manufacturing system (Slack & Lewis, 2015; Dangayach & Deshmukh , 2001). The decision to automate is dealt with in the manufacturing strategy decision area "process technology" (Hayes & Wheelwright, 1984; Skinner, 1969). However, automation decisions go beyond influencing this decision area solely (Winroth, et al., 2007). Aspects in other decision areas need to be considered and made compatible in order to utilize the competitive advantages of automation which can support manufacturing objectives (Gouvea da Costa & Pinheiro de Lima, 2008).

Despite this, automation decisions are still frequently viewed from a limited and inadequate perspective (Farooq & O'Brien, 2009). More often than not, the decision to automate is justified solely based on financial considerations, such as net present value (NPV), return on investment (ROI) and return on assets (ROA) (Farooq & O'Brien, 2009). As a result, some important aspects of manufacturing, that can affect or be affected by automation, are ignored (Machuca, et al., 2011; Jiménez, et al., 2011). Exactly what needs to be considered when making automation decisions is not well-defined, i.e. the content of automation decisions is unclear. There is need of further, more holistic knowledge to support decision-makers – the people that make decisions related to the automation of manufacturing – with automation decisions (Ortega, et al., 2012; Säfsten, et al., 2007). Including a holistic perspective can be valuable since the decision-maker needs information about what may have an impact on the decision to be made. When the decision-makers have the relevant information they need, it is possible to make so-called informed decisions.

Moreover, as mentioned previously, the overall manufacturing system design entails essentially a number of decisions, including those pertaining to automation. Previous literature shows that the way in which automation decisions are made has often been ad hoc and based on gut feeling, without the support of a structured process (Lindström & Winroth, 2010). Thus, the process leading to automation decisions is often unclear, providing limited support for practitioners. The lack of a structured process related to automation decisions in manufacturing system development projects might be a direct result of prioritizing product development over manufacturing system development, since it is seen as a means to achieve competitive advantages (Bellgran & Säfsten, 2010). The neglect of manufacturing system development has resulted in ad hoc practices, lack of structured approaches and difficulties in coordinating the manufacturing system development process (Rösiö & Bruch, 2018). To support companies achieve set targets, the process leading to automation decisions needs to be well-structured (Hamzeh, et al., 2018; Evans, et al., 2013). A well-structured process requires the decision-maker to systematically collect and process several types of information (Russo, et al., 2002). Thus, to support automation decisions that are sound, the constituent content of automation decisions should be processed in a systematic manner.

To tackle different challenges and utilize the advantages related to automation of manufacturing, companies are putting a lot of effort in to manufacturing development, in line with the German initiative Industry 4.0 (Kagermann, et al., 2013) and other similar initiatives related to what has been foreseen as the fourth industrial revolution (Gilchrist, 2016). In several industrial sectors, such as automotive, industrial automation and machine tools, successful work has been done (de Boer, et al., 2019). However, one sector that might have a longer way to go is the wood products industry (Landscheidt & Kans, 2016; Agenda Trä, 2013; NRA Sweden, 2012). Indeed, the wood products industry is characterized by a marked lack of knowledge and experience in driving manufacturing system development initiatives (Abu, et al., 2019). Moreover, the industry is also challenged by short-term goals and lack of strategies (Mattila, et al., 2016). Given that lack of knowledge and unclear strategies can result in difficulties in making informed automation decisions in manufacturing system development projects, supporting informed automation decisions in such projects might be particularly valuable in the wood products industry.

To summarize, investments in automation of manufacturing are commonly undertaken in connection to manufacturing system development projects. While some investments result in substantial benefits for companies, others fail to achieve the beneficial outcomes which are anticipated (Kumar, et al., 2017; Almannai, et al., 2008). The literature demonstrate that investments in automation of manufacturing are more likely to succeed if they are based on informed automation decisions where all aspects of the relevant issues are considered in a systematic manner (Hamzeh, et al., 2018; Machuca, et al., 2011). Making informed automation decisions can, however, entail different challenges. Currently, there is lack of a holistic understanding of what needs to be considered when automation decisions are being made and how the process leading to such decisions should be supported. In addition, few of existing research studies that examine automation decisions in manufacturing system development projects focus on specific industrial contexts (Ortega, et al., 2012), such as the wood products industry. The need for additional research is clear.

1.3 Purpose and research questions

The essential purpose of the research presented in this thesis is to support informed automation decisions in the context of manufacturing system development projects carried out in the wood products industry. The aim is to contribute with knowledge concerning the content and process of automation decisions. The following research questions were used to guide the research:

RQ1: What are the manufacturing challenges facing the wood products industry?
The first research question (RQ1) is intended to support and improve understanding of the industrial context studied through providing insights on manufacturing systems in the wood products industry by examining its challenges.

RQ2: What are the drivers and challenges for automation of manufacturing in the wood products industry?
The second research question (RQ2) intends to provide rich background information and a deeper understanding of manufacturing automation in the wood products industry by identifying its drivers and challenges. Determining the drivers for automation of manufacturing is expected to shed light on the perceived benefits which motivate automation, while the challenges emphasize the difficulties of automating. A greater understanding of drivers and challenges can provide valuable insights for decision-makers regarding why a company should invest further in the automation of manufacturing and what challenges need to be overcome.

RQ3: What content need to be considered when automation decisions are being made in the context of manufacturing system development projects carried out in the wood products industry?

The third research question (RQ3) is geared to increasing knowledge about the content of automation decisions. Better understanding the content of automation decisions provides decision-makers with information on what aspects should be considered when automation decisions are being made. This information aims to support the utilization of successful investments in automation of manufacturing in the wood products industry.

RQ4: How can the process leading to automation decisions in the context of manufacturing system development projects carried out in the wood products industry be supported?

The aim of the fourth research question (RQ4) is to increase knowledge of the process leading to automation decisions. Understanding such processes increases knowledge of their strengths and weaknesses, which can provide valuable insights on improvement opportunities regarding different steps and actions that can be taken to support automation decisions in the context of manufacturing system development projects carried out in the wood products industry.

1.4 Scope and delimitations

The research presented in this thesis was conducted in the wood products industry. The empirical studies were carried out in Sweden, a country that has a long and distinct tradition of refining the raw material provided by its forests (Swedish Forest Industries' Federation, 2013). However, the results presented here may also be of interest in the case of countries that present geographical and historical similarities with Sweden, such as Finland.

It must also be mentioned that this thesis is part of the industrial graduate school ProWOOD, which aims to increase competitiveness and support innovation in the Swedish wood products industry. Being part of ProWOOD enabled close collaboration with a number of Swedish manufacturing companies. The empirical data presented is primarily based on findings from manufacturing companies operating in different business areas of the wood products industry, such as furniture -and construction industry. The findings, however, are mainly obtained from one company, referred to here as *Company*

Main. Company Main manufactures sawn timber and other wood products such as floors, panels and moldings which are used in the construction industry.

Besides examining the wood products industry specifically, the research underlying this thesis focuses on automation decisions made in connection to manufacturing system development (Bellgran & Säfsten, 2010). Therefore, an additional delimitation of this thesis is related to the scope of manufacturing system development. The focus is placed on automation decisions in the early phases of manufacturing system development, i.e. manufacturing system design. Thus, the different activities related to the realization of a manufacturing system, such as the ramp-up, operation and operation refinement, are excluded (Attri & Grover, 2012).

Moreover, automation decisions are viewed as part of the manufacturing strategy decision area known as process technology. However, since automation decisions can affect and be affected by other manufacturing strategy decision areas such as human resources (Choudhari, et al., 2010; Winroth, et al., 2007), the focus is not solely on process technology.

Lastly, this thesis adopts decision-making theory for supporting the understanding of the process leading to automation decisions connected to manufacturing system development.

1.5 Thesis outline

The thesis consists of six chapters; for ease of reference, a brief description of each chapter is presented below.

Chapter 1. Introduction

The Introduction gives the background to the research, with an emphasis on the importance of, and challenges facing, the Swedish wood products industry. The background further stresses the crucial role of automation of manufacturing for the industry's competitiveness. Chapter 1 also highlights the problem area that links automation decisions to manufacturing system development work and emphasizes the importance of considering the content and process of such decisions. The purpose of the thesis and the research questions are presented, as is a description of the scope and delimitations of the research.

Chapter 2. Frame of reference

Chapter 2 starts with an introduction to the frame of reference that encompasses the two predominant theoretical fields for the research: manufacturing system development and manufacturing strategy. An additional theoretical field that is used and presented in the frame of reference is decision-making theory, with a focus on decision-making related to automation in manufacturing system development projects.

Chapter 3. Research method

Here, the research context is presented in more detail, as is the particular role of the researcher. Further, the research process is set out in detail, which provides an overview of the six research studies that underlie this thesis (referred to as research studies A–F). Each study is described at length including the aim, the research methods used and the data collection and analysis techniques. A discussion regarding the research quality concludes the chapter.

Chapter 4. Summary of papers

This chapter provides an overview of the seven appended papers to this thesis and presents the main findings of each paper separately.

Chapter 5. Discussion

The findings from the appended papers are discussed in relation to previous literature. Chapter 5 discusses the manufacturing challenges in the wood products industry, as well as the drivers and challenges for automation of manufacturing in this specific industrial context. This chapter also includes a discussion on the content and process of automation decisions.

Chapter 6. Conclusions

In this chapter conclusions are drawn regarding the findings. Further, an outline of the theoretical and industrial contributions is presented. The chapter discusses the limitations of the findings and provides directions for suggested future research.

2. Frame of reference

This chapter introduces the frame of reference for the thesis and includes a description of some of the characteristics of the manufacturing systems present in the wood products industry. The chapter further includes descriptions of theoretical fields related to manufacturing system development, manufacturing strategy and decision-making.

2.1 Introduction to the frame of reference

As the purpose of this thesis is to support informed automation decisions in the context of manufacturing system development projects carried out in the wood products industry, the research context is manufacturing system development projects carried out in the wood products industry and the topic of specific interest is automation decisions.

The frame of reference starts by providing some characteristics of the wood products industry with the emphasis on automation of manufacturing. Thereafter, to explore the topic of interest in greater depth, the frame of reference presents the theoretical fields which had different roles in the thesis.

The main theoretical field included in the frame of reference is manufacturing system development. Decisions that entail changes to the manufacturing system – such as automation decisions – are commonly made during manufacturing system development projects (Bellgran & Säfsten, 2010). The focus here is on the early phases of the manufacturing system development: the manufacturing system design. The reason for this is that in the early phases the conditions for a good manufacturing system are created (Bellgran & Säfsten, 2010).

A related field of importance is manufacturing strategy. Manufacturing strategy is an essential element to manufacturing system development. As mentioned in the introduction, to utilize in full the competitive advantages of automation, automation decisions need to be grounded in manufacturing strategy (Machuca, et al., 2011), which is the theoretical position adopted in this thesis. Automation decisions lie in the manufacturing strategy decision area process technology, one of several decision areas. However, previous studies agree that such organizational decisions can have correlations with other manufacturing strategy decision areas and must therefore be viewed in relation to them (Machuca, et al., 2011; Jiménez, et al., 2011). For this reason, the frame of reference is not limited to automation decisions solely, but rather views them in relation to other decision areas, such as human resources, vertical integration, etc. (Table 2.1).

Last, to extend the analysis, theory on decision-making is included. The focus is on using this theoretical field to provide the groundwork necessary for identifying the weak points and improvement opportunities regarding decision-making related to automation of manufacturing. An overview of the components included in the frame of reference is provided in Figure 2.1.

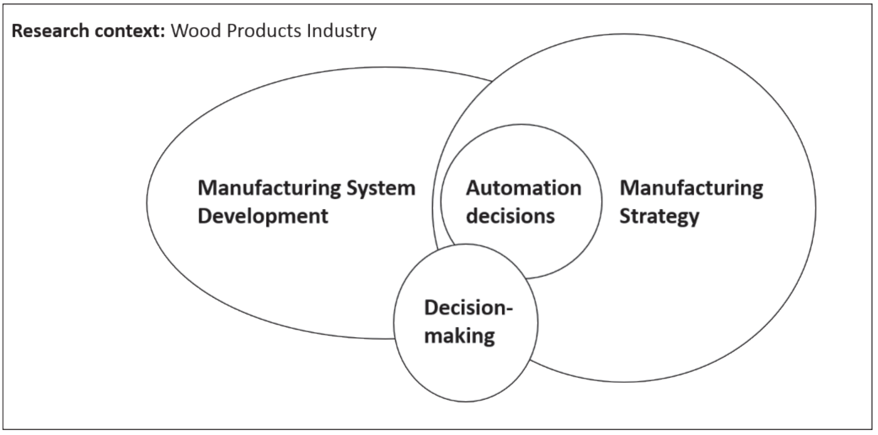

Figure 2.1 Overview of the frame of reference showing the role of different parts for the thesis

2.2 The wood products industry

The wood products industry includes companies of different sizes operating in several distinct business areas: a wide variety of materials, manufacturing processes and products can therefore be found in the manufacturing systems within the industry. Landscheidt and Kans (2016) systematize the status of automation practices in the wood products industry and compare it to other industries, such as the forest and automotive industries. Their findings show that the wood products industry implements lower levels of automation in manufacturing and that there is a clear stagnation in technology development. The authors stress the importance of overcoming this stagnation to achieve competitive manufacturing, especially in high-cost countries such as Sweden. They further elaborate on the opportunity for the industry to observe how other industries have implemented automation of manufacturing and through that adapt suitable concepts.

In general, investments in automation of manufacturing have been repeatedly cited as essential to strengthen the competitiveness of the wood products industry (Spetic, et al., 2016; Grushecky, et al., 2006). However, the industry faces different challenges. One of these challenges is the heterogeneous character of the raw material that is consumed in the industry (Karltun, 2007). There are several factors related to the raw material that can affect the manufacturing system, such as the biological effects of wood (knots and other natural defects), varying moisture content as well as origin and type of tree that affects different mechanical properties such as tensile strength, stiffness and durability (Eliasson, 2014). In a way, the wood industry is unique due to the characteristics of the raw material consumed: wood is organic and exhibits great heterogeneity, resulting in a highly variable raw material. This presents various challenges with respect to the quality and quality control of the products manufactured. This is especially true in the wood products industry, where waste and rework of the manufactured goods are prevalent (Kozak & Maness, 2003). Different automated solutions, such as X-ray and scanners, can be used to control the quality of the incoming raw material in a more accurate and effective way (Eliasson, 2014). Nevertheless, sorting and grading processes are difficult to automate since they require understanding of the acceptance tolerances which are associated with rejection rates and thus manufacturing costs (Eliasson, 2014). The variable characteristics of wood challenges the manufacturing system in aspects other than quality issues as well. Cutting forces and processing speed of automation of manufacturing is significantly lower in the wood products industry than, for example, in the metal industry (Karltun, 2007).

Another prevalent problem in the wood products industry regarding investments in automation of manufacturing is the labor force. The industry is characterized by rapid turnover of the labor force, and workers tend to have lower education levels, often missing certificates and operation licenses (Ratnasingam, 2015; Sowlati & Vahid, 2006). Training and education are therefore emphasized as essential to support the implementation of new automated solutions (Wiedenbeck & Parsons, 2010; Pirraglia, 2009). Wood products companies are struggling to meet their growth prospects (Kozak, 2005), and an unskilled workforce is emphasized as one of the biggest impediments (DeLong , et al., 2007).

The struggle of finding workers with the right competences might well persist in the future: the young generation with relevant education finds the wood products industry an unattractive employment prospect (Träregion Småland , 2014). One reason for that might be the tough work environment that prevails throughout the industry: its manufacturing systems are characterized by excessive noise, dust, heavy lifting and highly repetitive work tasks, which are a direct consequence of the low levels of automation in manufacturing (Karltun, 2007). Wood dust and the chemicals used (due to the handling of, for example, glue and paint in finishing operations) are health hazards, and the labor force exposed can suffer from serious health issues. Holcroft and Punnett (2009) state that the risk of accidents or work-related injuries is significantly higher in the wood products industry than in other industries. These tough – and unattractive – work conditions could be eliminated to some extent through increased levels of automation in manufacturing.

2.3 Manufacturing system development

Manufacturing system development involves the development of an existing or entirely new manufacturing system. It is triggered by different things, but one common reason is new product introduction. Manufacturing system development can be divided in terms of design and industrialization (Bellgran & Säfsten, 2010): the former includes work activities that are concerned with the planning of a manufacturing system, while the latter focuses on the implementation and realization of the system (Attri & Grover, 2012).

A process is commonly deployed for work activities related to manufacturing system development. The manufacturing system development process is usually treated as part of product development process, which is generally structured and includes several phases with related activities (Bellgran & Säfsten, 2010). In addition to the activities carried out, some decisions are made between the phases of the manufacturing system development process. Here, the activities that have been completed and the results that have been accomplished are evaluated in order to decide on whether the project should carry on to the next phase of the development process. The point where the decisions are made between two phases are referred to as a “gate”. This structure is commonly described as a stage-gate model (Ulrich & Eppinger, 2020). The execution of a development process, such as the manufacturing system development process, is often carried out in a project-led manner.

In this thesis, the focus will be on the early part of the manufacturing system development process: in other words, the manufacturing system design process. The reason for this is that the characteristics of the manufacturing system, and thus its ability to support a company's manufacturing strategies, are determined by its design (Bellgran & Säfsten, 2010). Thus, the manufacturing system design process can be a key facilitator of competitiveness (Koren & Shpitalni, 2010). Prior to proceeding with a description of manufacturing system design, a definition of a manufacturing system is provided.

2.3.1 Defining manufacturing systems

The term manufacturing system is often used interchangeably with the term production system. However, these two terms do not have precisely the same meaning. The main difference between manufacturing system and production system arises from the view of their scope. Two dominant perspectives currently exist: one considers the manufacturing system to be hierarchically superior to the production system (CIRP, 2020), while the other stresses the opposite – that the production system is hierarchically superior to the manufacturing system (Groover, 2015). Therefore, it is essential to specify which system is superior, and to define the hierarchical perspective (Bellgran & Säfsten, 2010).

This thesis will apply the notion that a production system is hierarchically superior to a manufacturing system. In this understanding, the manufacturing system is a subset of the production system. A system perspective is usually used to provide a holistic understanding of the manufacturing system. In the theory of technical systems presented by Hubka and Eder (1988), the manufacturing system is described as a transformation system that starts with an input (raw material) and ends with an output (finished product). Several distinct elements are involved to enable the transformation: the management system, the technical system, the information system and the human system. A system's perspective sets a limit between the system and its environment. The business environment exists outside of the system boundaries. A similar style of thinking can be noted in the socio-technical framework of Davis et al. (2014), as this model illustrates the manufacturing system as being embedded within an external business environment. The external environment involves regulations, suppliers, competitors and customers (Davis, et al., 2014).

2.3.2 Manufacturing system design process

The design of a system, such as a manufacturing system, can be defined as the conception and planning of the overall set of elements and events constituting a system, together with the rules for their relationships in time and space (CIRP, 2020). The manufacturing system design process refers to the process of creating a detailed description, also referred to as the specification, of the proposed manufacturing system. This description is based on a course of activities involving defining the problems, defining the objectives, outlining the alternative course(s) of action, evaluating the alternative course(s) of action, making choices among alternatives and creating a detailed design of the proposed manufacturing system (Bellgran & Säfsten, 2010).

As previously mentioned, manufacturing system design is the early part of the manufacturing system development process. The literature demonstrates that the overall development performance can be enhanced if manufacturing companies shift the identification and solving of problems related to manufacturing system design to earlier phases of the development process (Thomke & Fujimoto, 2000). Getting the right design *before* implementation facilitates it so that systems can be rapidly commissioned to allow for swift repayment of the invested capital as well as bringing new products to market promptly, resulting in a reduction in costs for the manufacturing company (Wu, 1994). Well-designed manufacturing systems are said to increase the possibility of achieving the best results (Bellgran & Säfsten, 2010).

2.3.3 Manufacturing system design challenges

Manufacturing companies are subject to various limitations when designing manufacturing systems. The previous literature concludes that the design of manufacturing systems generally takes place ad hoc, with no long-term or strategic approach (Bruch, 2012; Rösiö, 2012). Indeed, simple trial and error remains the most frequent way of designing manufacturing systems (European Factories of the Future Research Associat, 2016). These shortcomings are argued to be due to the prioritization of product design capabilities over manufacturing system design capabilities (Bellgran & Säfsten, 2010; Cochran, et al., 2001-2002). Manufacturing system design is usually treated as part of the product design rather than as a separate technical system that needs to be developed and implemented. The reason for manufacturing companies focusing on product design is because they see it as a way to achieve competitive advantages, while the manufacturing system design on the other hand is seldom seen as a means to achieve the best possible manufacturing system (Bellgran & Säfsten, 2010) and even less as a route to securing competitive advantage.

The limited attention that has been given to manufacturing system design has led to various consequences. It has been argued, for example, that the nature of the manufacturing system design process is not well defined, i.e. there are many different definitions and interpretations of the process and work activities involved (Cochran, et al., 2001-2002). Moreover, development process models seldom implement the decision-making methods and tools related to manufacturing system design; the primary focus lies on decision-making methods and tools for product development and project management. Without adequate support, many manufacturing companies find it difficult to coordinate the manufacturing system design process and work in a structured and systematic way (Cochran, et al., 2001-2002).

2.3.4 Activities in manufacturing system design process

The manufacturing system design process consists of a number of phases, and in each phase different activities are carried out to support the development work. In the literature, the manufacturing system design process has been explored and presented by multiple authors (Rösiö & Bruch, 2018; Bellgran & Säfsten, 2010; Wu, 1994). The different authors do not necessarily use the same terminologies and neither do they include the exact same number of phases or activities to be conducted. However, despite the differences in structure and terminologies, there are some common grounds. For example, the literature agrees that the manufacturing system design process includes, among other things, a development plan, setting a requirements specification and generating a system solution (Andersen, et al., 2017).

Bellgran and Säfsten (2010) present a structure for the manufacturing system 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. To further structure the manufacturing system design process, Bellgran and Säfsten (2010) suggest distinguishing between preparatory design and detailed design. The manufacturing system design process starts with preparatory design and ends with detailed design. Preparatory design comprises the two first phases which are background study and pre-study. Commonly, in the initial phases the focus is on assessing potential and formulating project definition. Other activities conducted during this stage include analyzing the present and future manufacturing system, setting objectives and formulating requirements specifications. Thereafter, the detailed design is initiated. Detailed design consists of the three last phases, starting with the design of conceptual manufacturing systems alternatives. Thereafter, in order to select a winning final solution, the alternatives are evaluated based on set evaluation criteria. Then, the detailed design of the chosen manufacturing system is conducted.

Although the different phases are presented separately, it must be noted that each phase in a manufacturing system design process is dependent on the compilation of the previous one. For this reason, the literature argues for the necessity of working in an iterative manner (Bellgran & Säfsten, 2010; Wu, 1994). Figure 2.2 summarizes some typical activities carried out during a manufacturing system design process and provides the literature references where these were found.

	Typical activities	References
Background study	• Exploration and generation of ideas • Informal discussions • Benchmarking • Product analysis	(Rösiö & Bruch, 2018; 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, 2018; 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, 2018; 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, 2018; Bellgran & Säfsten, 2010; Wu, 1994)

Figure 2.2 Some typical activities in a manufacturing system design process

2.3.5 Different approaches to manufacturing system design

Accomplishing the activities in a manufacturing system design process often requires the involvement of different resources, both internal resources within a manufacturing company as well as external resources, such as those provided by suppliers. Based on the degree of involvement by the manufacturing company in the activities carried out during a manufacturing system design process, three main approaches to manufacturing system design are identified in the literature (Bellgran & Säfsten, 2010): (1) Concept-generating approach, (2) Concept-driven approach and (3) Supplier-driven approach.

In a concept-generating approach the manufacturing company is involved and is thus responsible for all activities in the different phases prescribed in general manufacturing system design process (see Figure 2.3A). The manufacturing system design process is guided by various requirements, such as the type of product, volume and number of variants. The generated concepts are compared during the manufacturing system design process based on the decisions that are made and the requirements that are set until one final concept remains.

In a concept-driven approach, the manufacturing system design is carried out by the manufacturing company. However, the design process is driven by something external, such as a pre-existing design or the interests of an involved actor (Engström, et al., 1998). When a concept-driven approach is applied, a preferred manufacturing system solution or a concept is given from the beginning of the design process. For this reason, the conceptual design phase in the general manufacturing system design process is more or less not considered or completely excluded (see Figure 2.3B).

The supplier-driven approach is common. This is so since more and more manufacturing companies are deciding not to design their manufacturing system without external help, such as that provided by automation suppliers. Thus, in the supplier-driven approach, part of the design, or in some cases most of the design of the manufacturing system is handed over to suppliers; the degrees of involvement of the manufacturing company in supplier-driven approach can therefore vary. When a supplier-driven approach is applied to the degree where all design activities are outsourced, the manufacturing system design process becomes a “black box” from the perspective of the manufacturing company. Note that in these situations it is critical that the manufacturing company should still maintain certain in-house competencies in order to benefit from the supplier integration (von Haartman & Bengtsson, 2009). In general, in the supplier-driven approach, the manufacturing company sets the objectives and provides a more or less detailed requirements specification of the manufacturing system. Based on this, the suppliers develop their manufacturing system solutions. As a result of the supplier-driven approach, the supplier presents several alternative solutions that are later evaluated by the manufacturing company. The evaluation is found to focus on two main perspectives: the fulfillment of the requirements specification and the reliability, trustworthiness and cooperativeness of the supplier. When the supplier-driven approach is applied, the manufacturing company is commonly more involved in the beginning of the design process where the objectives are set and later when alternative solutions for the manufacturing system are evaluated – see Figure 2.3C.

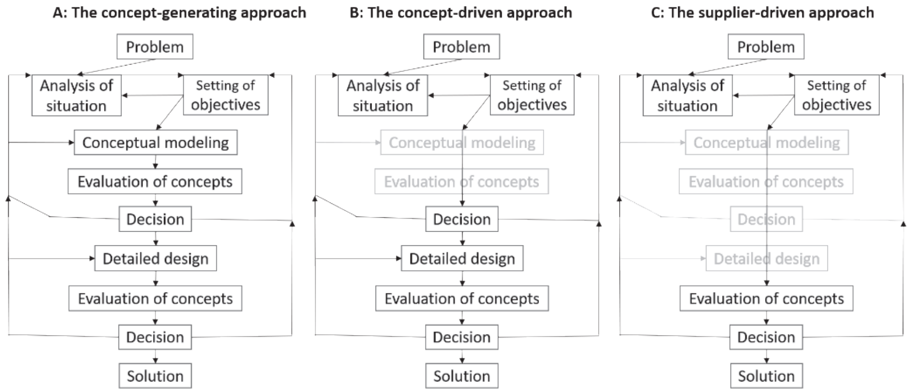

Figure 2.3 The three approaches to manufacturing system design from the manufacturing company's perspective (Säfsten, 2002)

2.3.6 Decisions in manufacturing system design process

Investments in the automation of manufacturing can have significant effects on a company's competitive advantages. Therefore, manufacturing system design involving new automated solutions are emphasized as important (Arana-Solares, et al., 2019). However, companies cannot safely assume that developing manufacturing systems involving new automated solutions will systematically lead to increased competitiveness (Olson, et al., 2014).

Decisions made during manufacturing system design processes have an important role in achieving desirable results. As mentioned earlier in this chapter, several decisions, including automation decisions, are made at different stages during the manufacturing system development process. The decisions that are emphasized as especially crucial for achieving competitiveness are those made early on – i.e. the decisions that are made during the manufacturing system design process. This is because these early decisions have a crucial impact on how the final manufacturing system will look and operate (Choudhari, et al., 2010). Moreover, the ability to make major changes regarding those decisions later on, when the manufacturing system is in operation, is limited, mostly due to cost and time restrictions. Therefore, decisions made during a manufacturing system design process are emphasized by a number of researchers as significant to achieve the best results, and thus improve competitive advantages (Slack & Brandon-Jones, 2019; Bellgran & Säfsten, 2010).

Careful consideration of decisions made during any manufacturing system design process is important: these decisions involve commitment to actions which might lead to compromises and trade-offs (Pooya & Faezirad, 2017; Skinner, 1969). This in turn can affect the achievement of competitive advantages. Previous literature argues for the need to link decisions made during the manufacturing system design process to a company's manufacturing strategy (Eisenhardt & Zbaracki, 1992). The reason being that although there are some best practices that can be shared to some extent across different industrial sectors, due to the complexity of decisions there is not one solution that can fit all (Attri & Grover, 2012). Therefore, decisions made in the design process need to be in line with the purpose of the manufacturing system to be developed. Moreover, to enable competitiveness, there is a need to have a holistic perspective when making these decisions, where the different aspects of a manufacturing system and their interrelation are considered (Díaz Garrido , et al., 2007).

2.4 Manufacturing strategy

An essential element related to manufacturing system development is manufacturing strategy, i.e. how a company intends to compete in the market (Bellgran & Säfsten, 2010). The manufacturing system is one of several functions that must support the achievement of a company's overall objectives. If run properly, the manufacturing system can lead to better performance. A coherent strategy that is implemented well can help secure potential competitive advantages (Thun, 2008). Skinner (1969) was a pioneer in grasping the importance of manufacturing strategy by realizing that it was the missing link between manufacturing and corporate strategy. The notion of manufacturing strategy has held an important role in the domain of operations management ever since. However, manufacturing strategy has been differently defined by various authors. Generally, the definitions emphasize that it should include a description of competitive priorities and have a long-term scope. A comprehensive definition applied in this thesis is that provided by Hill and Hill (2009):

> [manufacturing strategy is] a series of decisions concerning process and infrastructure investment, which, over time, provide the necessary support for the relevant order-winners and qualifiers of the different market segments of a company. (Hill & Hill, 2009, p. 61)

2.4.1 Manufacturing strategy decision areas

Manufacturing strategy is commonly divided in terms of content and process (Slack, et al., 2010). Manufacturing strategy content includes competitive priorities and decision areas (Slack & Lewis, 2019). The most commonly listed competitive priorities are cost, quality, delivery and flexibility (Slack & Lewis, 2019; Acur, et al., 2003; Dangayach & Deshmukh , 2001). The decision areas are usually distinguished in terms of structural and infrastructural elements and aim to support a company's capabilities and meet its overall business objectives (Miltenburg, 2005; Slack & Lewis, 2019). Structural decision areas determine the physical attributes of a company and often require a substantial capital investment (Hayes, et al., 2005). These decision areas are usually characterized by their long-term impact. Infrastructural decision areas refer to tactical activities and do not often require extensive capital investment (Hayes & Wheelwright, 1984). It is important to note that the focus should not be shifted toward only structural or infrastructural issues, but rather consider the right combination of decision areas. Capacity, vertical integration, facility and process technology are some of the most common structural decision areas. In contrast, quality management, production planning and control, human resources and organization are acknowledged when infrastructural decisions are detailed.

Decisions made during a manufacturing system development process that are related to the different manufacturing strategy decisions areas will determine what a manufacturing system will look like and how it will operate (Choudhari, et al., 2010). It must, then, be noted that decisions made in one decision area can affect others. Thus, the interrelation of the different decision areas in a manufacturing system must be considered to facilitate an increased competitive advantage.

An overview of some of the most common decision areas and their included considerations are provided in Table 2.1. The exact terms and definitions for the different decision areas may vary among sources; however, the sources often share more or less congruous views.

Table 2.1 Manufacturing strategy decision areas

Decision areas	Included considerations	Mentioned by
Organization	Centralized versus decentralized organization, roles of staff groups and structure, relationships between groups and decisions	(Slack & Lewis, 2019); (Hayes, et al., 2011); (Miltenburg, 2005)
Process Technology	Levels of automation, interconnectedness, type of manufacturing technology, choice of equipment, lead versus follow	(Slack & Lewis, 2019); (Hayes, et al., 2011); (Miltenburg, 2005); (Skinner, 1969)
Vertical Integration	Make versus buy, supplier selection, supply network	(Slack & Lewis, 2019); (Hayes, et al., 2011); (Miltenburg, 2005)
Human Resources	Skill levels, wages, training and development, promotion policy, employment security	(Hayes, et al., 2011); (Miltenburg, 2005)
Production Planning and Control	Purchasing, planning, scheduling, material control systems	(Hayes, et al., 2011); (Hayes & Wheelwright, 1984)
Quality Management	Quality assurance, quality control policies and practices, responsibilities and reporting	(Hayes, et al., 2011); (Miltenburg, 2005); (Hayes & Wheelwright, 1984)
Facility	Size, location, specialization	(Hayes, et al., 2011); (Miltenburg, 2005)
Capacity	Amount, type, acquisition time	(Slack & Lewis, 2019); (Hayes, et al., 2011)

2.4.2 Automation decisions

Automation decisions are dealt with in the manufacturing strategy decision area process technology (Miltenburg, 2005). Process technology has traditionally been concerned with the machines and equipment that shapes, transports, stores or in any way changes the physical object. This definition needs to be expanded since automation replaces, to some degree, not only the physical, but also the cognitive human labor (Parasuraman, et al., 2008;

Sheridan, 2002), which is concerned with the collection, storage and distribution of information. In this thesis, all physical and cognitive tasks that support manufacturing systems, and are not performed by human labor, are defined as automation.

The decision to automate can be initiated at different levels within a company. A top-down approach starts at top management level, whereas a bottom-up approach begins with the labor force working at lower levels of the organization (Groover, 2015). A top-down initiation will focus on increasing labor productivity, reducing labor costs, improving product quality, reducing manufacturing lead-time and avoiding the cost of not automating. In contrast, automation that is implemented bottom-up will focus on minimizing the effects of labor shortages, reducing or eliminating manual tasks, improving labor safety and accomplishing processes that cannot be done manually (Groover, 2015). Optimally, there should be a shared view at the operational and managerial level on why the company should invest in further automation of manufacturing. Understanding operational needs is crucial for the managerial level to form successful strategic organizational decisions (Edh, et al., 2016), such as automation decisions. Furthermore, the decision-makers must take into consideration that adjusting in one of the manufacturing strategy decision areas may have implications for other decision areas (Choudhari, et al., 2010). For example, if introducing automated solutions that the labor force is unfamiliar with, the decision-makers must consider the human resources aspect (Nujen, et al., 2018). Thus, when making automation decisions, there is a need for a broader overview than focusing on process technology solely (Winroth, et al., 2007).

To support automation decisions, the previous literature emphasizes the importance and need for a strategy (Lindström & Winroth, 2010). Frohm (2008) points out that one of the main reasons why automation investment projects fail is due to undefined objectives. Specification of requirements that are well formulated and detailed are therefore emphasized to be of great importance (Granlund & Friedler, 2012). Moreover, it is stressed that successful automation decisions, realizing investment goals and strengthening competitive advantages, are those that are closely aligned with the company's capabilities as well as its business and manufacturing strategies (Garrido-Vega, et al., 2015; Winroth, et al., 2007). Therefore, companies need to develop their automation strategies prior to investing in automation of manufacturing. This is, however, rarely observed in the industry (Granlund, 2011). Often, automation decisions are rather made ad hoc or based on previous experiences rather than solid facts and a well-defined strategy (Winroth, et al., 2007). Previous research output has attempted to support the industry in the development and formulation of an automation strategy. However, support appears to be somewhat lacking when viewing the actual content of automation strategies (Granlund, 2011; Säfsten, et al., 2007).

2.5 Decision-making

A decision can be described as ‘‘a commitment to a course of action that is intended to yield results that are satisfying for specified individuals’’ (Yates, 2003, p. 24). Decision-making is the process of making choices, and this is a central part of strategic organizational actions and long-term competitiveness (Gavetti, et al., 2007). Decision-making generally requires the decision-maker to collect and process several types of information (Russo, et al., 2002) in order to evaluate different options and make a final choice.

2.5.1 Decision-making in manufacturing design

In a manufacturing system development project context, the manufacturing system design entails that essentially a number of decisions are to be made in order to achieve a stated target (Jonassen, 2012). Examples of such decisions include layout, levels of automation and work organization (Bellgran & Säfsten, 2010). Collecting and processing the information gathered to finalize the different decisions can require substantial resources. Moreover, the evaluation of the information gathered regarding the different options available may change depending on alternative possible scenarios related to the development work. Finalizing the decision may require the decision-maker to assess the relative likelihood of the different possible scenarios emerging (Lehto, 2001). Similarly, the ranking of different alternatives may change depending on the criterion considered. The decision-maker may also find it necessary to exert effort and invest resources to reduce uncertainty about their own personal preferences and aspirations, which may be particularly strong if they face unfamiliar scenarios and/or scenarios that contain several hypothetical elements (Lehto, et al., 2012).

A further challenge that may be encountered is that the alternative options available may be evaluated differently by the different stakeholders involved in the decision-making, even in a given scenario (Firouzabadi, et al., 2008). In the context of manufacturing system design, the involvement of several stakeholders when making decisions is common. For example, in a development project the management and the employees may hold different views on decisions related to whether to carry out some activities in-house or to outsource them. In the case of decisions made by committees, diverging views may find their expression in the opinions voiced and the votes cast by the stakeholders' representatives, and the actual decisions made are generally compromise solutions (Lehto, 2001).

2.5.2 Decision-making approaches

The different tools and methods used to guide decision-makers to make more appropriate decisions can be categorized in two distinct approaches. The first approach involves normative or prescriptive decision-making, where the goal is to provide guidelines on how people should make decisions (Badiru, 2014; Lehto, et al., 2012). Normative decision-making approaches view the decision-makers as rational and fully informed (Jonassen, 2012). They assume that the decision-makers make decisions through identifying the best alternative out of a larger set of alternatives that maximizes the value of the decision in any uncertain situation. In order to compare and choose the best alternative, usually the different set of alternatives are assigned numerical values to support the decision-making. The benefit of these decision-making approaches is that they produce relevant insights and help to base decisions on solid facts (Liberatore & Luo, 2010). However, normative decision-making approaches may not be adequate in all situations involving manufacturing system design (Loch, 2017; White, 2016). Reliance on normative decision-making approaches can be problematic since given its systematic and structured nature it is often described as a slow, effortful and time-consuming (Dane & Pratt , 2007). Therefore, this option might not always be appropriate when dealing with time-pressured situations and the need to effectively handle problem solving under conditions of uncertainty (Luoma, 2016). In addition, normative decision-making approaches rarely consider the decision-maker's sense of intuition when under conditions of risk and uncertainty (Bai & Sarkis, 2017). Taking the decision-maker's intuition into consideration is crucial since most of the information required to make decisions in the manufacturing system design process can only be found in the minds of experienced system designers (Bellgran, 1998).

The second approach involves descriptive or naturalistic decision-making; this emphasizes how people *actually* make decisions rather than how people *should* make decisions (Jonassen, 2012). Descriptive and naturalistic decision-making approaches highlight that the decision-makers are seldom as rational as normative models assume. Their decisions are rather influenced by unconscious drivers and emotions, as well as previous experiences (Dane & Pratt , 2007). This approach is associated with having a strong hunch or feeling of knowing what is going to occur. Making decisions based on intuition can be advantageous when decision-makers are dealing with time pressures and possess significant experience in a particular field (Elbanna, et al., 2013; Gore & Sadler-Smith, 2011). However, descriptive or naturalistic decision-making approaches have their disadvantages. Decision-makers who rely too much on intuition, might ignore relevant facts, resulting in misjudgments and the inevitable later difficulties in explaining the reasons for making certain choices (Elbanna, et al., 2013; Dane, et al., 2012). For a complex problem which requires a decision or series of decisions, such as manufacturing system design, a risk in relying solely on intuitive decision-making is that not all relevant information is taken into account.

In practice, the gap between "rational" and "intuitive" decisions is not as large as is commonly perceived. The practical limitations that actual decision-makers face in terms of time, information and computational capacities usually lead to the use of fast and frugal heuristics, namely “inference mechanisms that can be simple and smart” (Gigerenzer, et al., 1999, p. vii). Gigerenzer et al. (1999) describe fast and frugal heuristics as simple decision strategies that are part of a decision-maker's repertoire of cognitive strategies employed for making judgments and decisions. Examples of heuristics are “educated guesses, rules of thumb, trial and error, and stereotyping and profiling” (Hamilton, 2016, p. 18). These mechanisms are adapted to the observed empirical patterns, and usually do not make explicit references to the formal laws of logic and probability. Many authors have observed that the use of heuristics can lead to systematic biases, and thus to potentially predictable errors – see for example Kahneman (2011). These errors are often the expression of inaccurate extensions of heuristics from settings in which they were developed and tested to new settings where they can lead to systematic biases, which may in turn cause systematic errors (Gigerenzer, et al., 1999; Nisbett & Ross, 1980; Tversky & Kahneman, 1974). For example, heuristics that allow a company to identify valuable business opportunities in a given environment may mis-perform in a new market, or a R&D policy that was successfully used by the company in a specific technological scenario may become inadequate during a period of rapid technological changes.

The tendency to extend specific heuristics to contexts that would require either adjustments to them or possibly a substantially different approach is observed both in the case of individuals and in the case of committees and organizations (Garicano & Posner, 2005; Surowiecki, 2004). Analyses carried out by teams may be subject to "herding" or "groupthink," whereby the reliability and/or precision of pieces of information available to single team members are underestimated. The given pieces of information are therefore not adequately incorporated into the pool of information on which the team's decision is based (Banerjee, 1992; Welch, 1992), and the potential benefits from the multiple points of view available may therefore be only partly realized. These biases can be predicted and tackled through the support of systematic decision-making models.

From a manufacturing system design perspective, the use of fast and frugal heuristics is seldom encouraged, neither in theory nor in practice (Rösiö, et al., 2015). The logics used in fast and frugal heuristics are opposites of the normative, rational decision-making approaches which traditionally have been strived for when making strategic decisions in organizations (Cabantous & Gond, 2011). However, in practice both rationality and intuition are used depending on the level of uncertainty that prevails. While some decisions in manufacturing system design must be grounded in rational logic, other decisions often need to be made based on "intuition" and even "guessing" (Simon, 1997, p. 24) connected to manufacturing system designers' previous experiences and knowledge (Bellgran, 1998). To support decision-making during the design of manufacturing systems, rationality *and* intuition need to be considered together rather than separately.

3. Research method

In this chapter the role and position of the researcher is presented. Further, the research process is described providing an overview of the six research studies that underlie this thesis (referred to as research studies A–F). This is followed by a detailed description of each research study conducted where the research method and the data collection and analysis techniques are explained. The chapter concludes with a discussion regarding the research quality.

3.1 Role and position of the researcher

This thesis was conducted within the distinct educational context of ProWOOD, which is an industrial graduate school and a collaboration between the Knowledge Foundation, Jönköping University, Linnaeus University, Nässjö Träcentrum and several companies and research institutes. The broad aim of ProWOOD is to increase the competitiveness and innovative capacity of the Swedish wood products industry. Each doctoral student within the graduate school collaborates with either a company or a research institute. The research projects carried out by the doctoral students are jointly formulated by the industry and academia. The author of this thesis did her doctoral study in collaboration with a large Swedish wood products company that manufactures sawn timber and other wood products used in the construction industry: this company is referred to throughout the text as Company Main. The author dedicated 80% of her time to research and 20% to administrative work. Until the licentiate thesis was presented, the administrative work involved teaching – thereafter this shifted to working on projects at Company Main.

During the research process the role of the researcher changed: until the licentiate thesis was presented, the researcher had more of an observer's role at Company Main; the aim was to get acquainted with the salient industrial characteristics of the Company and to gain deeper knowledge of automation of manufacturing in the specific industrial context without interfering with it. After the licentiate thesis, the aim was to increase understanding of the content and process of automation decisions in manufacturing system development projects carried out in the wood products industry. This goal was partly addressed through studying two manufacturing system development projects conducted at Company Main, referred to as Project Wood and Project Wood2 in this thesis. The researcher was actively integrated in these projects by being invited to different meetings, including project and steering group meetings. This enabled the researcher to become intimately acquainted with the projects' organizations, which in turn opened the way for opportunities involving informal dialogues with the practitioners; these exchanges provided valuable insights on the phenomenon under study. The researcher's role during this time shifted, so that on some occasions the researcher observed and took notes during meetings while at other times the researcher was involved in initiating meetings and facilitating discussions. This put different demands on the researcher since she had to continuously balance her distance from and closeness to the practitioners by being active but not controlling.

3.2 Research process

The research process can be divided into two main phases. The first phase resulting in a licentiate thesis, and the second phase resulting in a doctoral thesis. To address the four research questions posed, six research studies were conducted resulting in seven papers, collectively referred to as research studies A–F and Papers I–VII. Figure 3.1 shows the links between the research questions, research studies and papers appended.

	Research study A	Research study B	Research study C	Research study D	Research study E	Research study F
RQ1	Paper I	Paper II				
RQ2			Paper III			
RQ3				Paper IV	Paper V, Paper VI	
RQ4					Paper VI	Paper VII

Figure 3.1 The links between the research questions, research studies and appended papers

In the first phase of the research process, research studies A–C were conducted. Research studies A–C looked at the manufacturing context in the wood products industry, with the focus on different areas. Research study A aimed to identify the manufacturing challenges and was conducted between September 2014 and May 2015. The outcome of research study A contributed to answering RQ1, resulting in Paper I. Research study B studied the impact of the raw material on manufacturing system performance. The outcome contributed to answering RQ1, resulting in Paper II. Research study C aimed to identify the drivers and challenges for automation of manufacturing in the wood products industry and was carried out between August 2015 and June 2016. The outcome of research study C contributed to answering RQ2, resulting in Paper III. The first phase of the research process was finalized in mid-2017 by presenting the licentiate thesis, titled "Exploring aspects of automation decisions: A study in the Swedish wood products industry" (Salim, 2017). One of the conclusions drawn from the licentiate thesis was that new and efficient automation of manufacturing is essential to support the development and maintain the profitability of the wood products industry. However, the findings showed that companies operating in this industry were facing several challenges, one of them being that they had difficulties supporting automation decisions. Indeed, decisions on automation in the wood products industry tended to be based simply on "gut feeling" and previous experience, rather than well-defined decisions, a coherent rationale and strategic goals.

Research studies D–F were initiated after the licentiate thesis. Research study D aimed to examine the content of automation decisions from a manufacturing strategy perspective, in order to identify the aspects that need to be considered when such decisions are being made. Research study D was conducted between September 2017 and December 2018, confirming a lack of knowledge in the research area and revealing the potential benefits that companies can gain by anchoring automation decisions in manufacturing strategy. The outcome of research study D contributed to answering RQ4 and resulted in Paper IV. Research study E aimed to examine the content and process of automation decisions in manufacturing system development projects in the wood products industry. The study was conducted between June 2017 and December 2019. The findings contributed to answering RQ3 and RQ4, resulting in Paper V and Paper VI. Lastly, research study F aimed to examine the process of automation decisions in manufacturing system development projects carried out in the wood products industry and the automotive industry. Research study F was conducted between May 2019 and April 2020. The findings derived from research study F contributed to answering RQ4 and were presented in Paper VII. The timeline of the research studies is schematically illustrated in Figure 3.2.

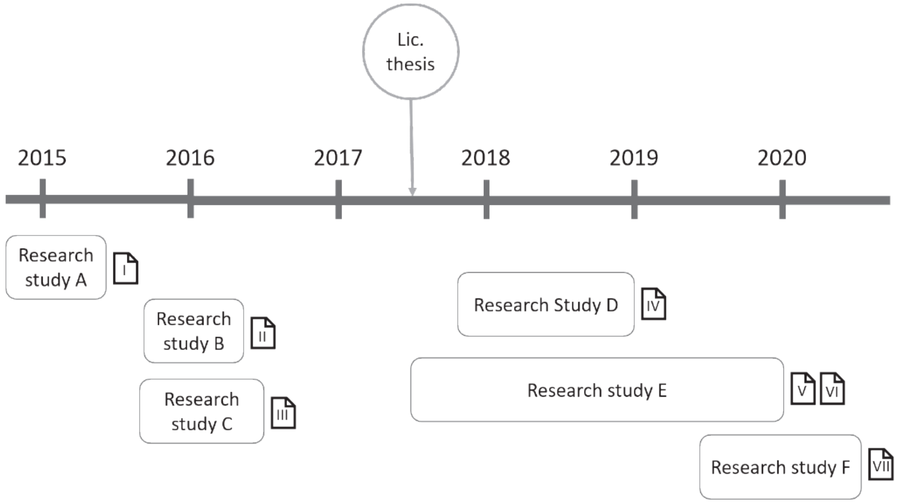

Figure 3.2 Timeline of research studies A–F

3.3 Research study A

Research study A was a case study combined with a traditional literature review. The literature review provided an understanding of the existing body of published work (Karlsson, 2016), while the case study provided a rich set of data from actual practice; the combination facilitates understanding of the phenomenon studied in an industrial context that is poorly understood (Säfsten & Gustavsson, 2020). The case study was performed at Company Main to investigate the contextual influence, both geographical and industry-specific, in relation to the literature. A unit of analysis connected to the aim and research question posed in research study A was selected to gain a focused understanding of the fundamental problem studied (Yin, 2018). The unit of analysis was the manufacturing system, since the study aimed to gain a holistic understanding of the current state of manufacturing in the wood products industry.

3.3.1 Collection of primary data

Face-to-face semi-structured interviews with open-ended questions (Newcomer, et al., 2015) were conducted with respondents that represented an array of roles from the operational to the managerial level (Table 3.1): manufacturing planner, quality inspector, plant manager, operator, technical manager, team leader and business manager. The manufacturing challenges were explored in terms of current and future challenges. Future challenges were defined as challenges that would arise five to ten years from the time that the study was conducted. The manufacturing challenges were studied within the basic components of a manufacturing system that allows the transformation of raw material into a finished product (Bellgran & Säfsten, 2010). The interviews were audio recorded and later transcribed into text as a foundation for the data analysis.

Table 3.1 Interviews in research study A

Role of respondents	Number of interviews	Total length of interviews
Manufacturing planner	1	1h 10min
Quality inspector	1	1h 03min
Plant manager	1	55min
Operator	4	3h 42min
Technical manager	1	56min
Team leader	1	44min
Business manager	1	55min

3.3.2 Collection of secondary data

The literature review in research study A utilized three main search terms: “wood products industry”, “manufacturing challenges” and “competitiveness”. Several synonyms were also included, such as: “wood processing industry”, “wood manufacturing industry”, “woodworking industry”, “secondary wood products industry”, “production challenges” and “productivity”. The searches used Boolean connectors and were conducted in Scopus, Web of Science and Google Scholar. The inclusion criteria were: that the publications were in English, covered the wood products industry and dealt with manufacturing systems. Since research covering manufacturing systems in the wood products industry was found to be scarce, the search was not limited to certain types of publication. Instead, several types of publications were included, such as journal articles, conference papers, theses, books and reports. No time limits were set. The evaluation process began with a title and abstract screening. Thereafter, if the source was initially deemed as relevant, the introduction along with the discussion and conclusions were screened to determine whether the source could profitably undergo a full content analysis. A citation search (Rumsey, 2008) was applied to relevant sources.

3.3.3 Data analysis

The primary and secondary data was analyzed according to the model outlined by Miles et al. (2019). The data analysis consisted of three phases: (1) data reduction, (2) data display and (3) conclusion drawing and verification.

In the first phase, data reduction, the data was reviewed and condensed down to information related to manufacturing challenges in predefined categories. The categorization of the manufacturing challenges was based on literature that emphasizes the five basic components of a manufacturing system (Bellgran & Säfsten, 2010): the human system, the technical system, the information system, the material handling system and the management system. Captured data that did not fit into these categories were placed under "others". The data was gathered in a Microsoft Excel sheet; this allowed the collected data to be displayed in the second phase: the data display. The data display phase, during which the data was visualized, made it easier to process the data and draw conclusions. The final phase, that of conclusion drawing and verification, was based on the patterns identified in the collected data as well as the results of relating the empirical findings to the literature. The three phases mentioned by Miles et al. (2019) were used in an iterative manner until final conclusions were drawn and verified.

3.4 Research study B

Research study B was a case study. The case study method was selected since it is a flexible research approach that allows the researcher to explore certain areas in more detail under the data collection process (Williamson & Johanson, 2017). The case study was performed at Company Main. The unit of analysis was the manufacturing system. As an embedded unit of analysis, the impact of the raw material on the manufacturing system performance was selected.

3.4.1 Data collection

The case study consisted of document analysis and face-to-face interviews. The document analysis examined how the raw material properties impact manufacturing productivity and efficiency. Two wood panels (finger-joint and solid) that differ in terms of the incoming material properties were selected. The panels were processed by the same machines. The finger-joint panel was delivered to the customer with a moisture content of 8–10%, finger–jointed, knot-free and only cover painted. The solid panel was delivered to the customer with a moisture content of 16–18%, solid, knotty and without a surface finish. The analyzed documents comprised historical data that the case company had gathered. The documents provided information about process productivity and efficiency based on stop time, product yield and manufacturing/machine hour. The stop time referred to the reasons for halting manufacturing, how many times manufacturing was stopped for each reason and the duration of each stop. The product yield referred to product qualities (Premium, Medium and Scrap) and the percentage of each class of quality in the analyzed orders. Premium represents the best quality, followed by Medium, while Scrap was as the name suggests: scrap. The machine hour category referred to the number of running meters of the respective quality manufactured per machine hour. Both of the analyzed panels were produced in the same amount of running meters: 343 000 rm. There were a total of 13 and seven orders analyzed for the finger-joint and solid wood panels, respectively.

Face-to-face interviews with open-ended questions were conducted to investigate other factors related to the raw material that impacted manufacturing system performance (Table 3.2). The respondents fulfilled a variety of roles at the company: manufacturing planner, plant manager, operators and manufacturing engineers. The interviews focused on the operational level because this was the level at which knowledge of the process-related factors that affect how raw materials influence the manufacturing outcome was available.

Table 3.2 Interviews in research study B

Role of respondents	Number of interviews	Total length of interviews
Manufacturing planner	1	31min
Plant manager	1	29min
Operators	2	46min
Manufacturing engineers	2	54min

3.4.2 Data analysis

Quantitative data analysis was applied to the examined documents. Descriptive statistics were used to calculate the productivity and efficiency variations of produced orders in terms of yield and machine hours for both finger-joint and solid wood panels. The stop time for each panel as well as the reason for each stop time was provided. The yield of the panels was presented as the percentages of each quality class. This enabled the comparison of different productivity and efficiency values for the selected and examined wood panels. The interview data was analyzed based on the three steps of qualitative data analysis outlined by Miles et al. (2019).

3.5 Research study C

Research C was a multiple case study. A case study method was applied due to the evident lack of empirical studies exploring the drivers and challenges for automation of manufacturing in the wood products industry – the case study method is appropriate when the topic under consideration has not been researched extensively (Williamson & Johanson, 2017). Another reason for choosing the case study method was to gain a rich set of data for understanding the phenomenon under study (Säfsten & Gustavsson, 2020) through a flexible research approach that allows research questions and data collection techniques to evolve during the research process. A multiple case study design was applied since evidence from various cases is more compelling (Yin, 2018). In addition, studying multiple cases enabled the evaluation and comparison of four large companies that operated in different business areas within the wood products industry. This inclusion was sought to broaden the perspective of the sample selection. The unit of analysis was the manufacturing system; as an embedded unit of analysis, automation of manufacturing was selected. Research study C explored large wood products companies with manufacturing systems located in Sweden.

3.5.1 Data collection

The data in research study C was mainly collected through face-to-face semi-structured interviews (Newcomer, et al., 2015). In each case company, respondents with different roles were interviewed to capture both the operational and managerial point of view on the topic of interest. Table 3.3 provides an overview of the case companies and their business areas of operation, the number of respondents that participated in the study and their roles in each respective company.

Table 3.3 Interviews in research study C

Company	Business area	Number of interviews	Role of respondents
Company Main	Interior products	13	4 Operators 1 Manufacturing team leader 1 Quality inspector 1 Manufacturing planner 6 Senior managers
Company Widows & Doors	Windows and doors	6	3 Operators 2 Manufacturing team leaders 1 Senior manager
Company Furniture	Foil-wrapping of furniture	5	2 Operators 1 Manufacturing team leader 2 Senior managers
Company Construction	Construction	2	2 Senior managers

In research study C, two students conducting their master’s theses were involved. For this reason, it was important to develop a structured basis for the data collection. The doctoral student of this thesis co-supervised the master’s students in their thesis work and together with them developed the interview guide. The master’s students conducted the interviews, and the doctoral student participated in conducting all the interviews at Company Furniture and the interviews with the operators and manufacturing team leader at Company Main. The interviews were audio recorded and transcripts were made shortly after as a foundation for the data analysis. The doctoral student analyzed the data for the purpose of Paper III, appended in this thesis.

To capture a holistic understanding of the drivers and challenges for automation of manufacturing, a systems perspective was applied. The drivers and challenges for automation of manufacturing were examined in terms of whether they were internal or external to the company. In addition to the interviews, data was collected through direct observations at the respective case company and by thoroughly reviewing documentation. While the interviews comprised the foundation of the data collection, the direct observations enriched the acquaintance with the manufacturing systems studied by observing type of flow, levels of automation, internal logistics and physical workload. The documents provided additional understanding; they included annual reports, company brochures and also company websites, all providing information about company goals and visions.

3.5.2 Data analysis

The collected data was analyzed according to the three phases of qualitative data analysis model outlined by Miles et al. (2019): (1) data reduction, (2) data display and (3) conclusion drawing and verification.

In the phase of data reduction, the data was reviewed and condensed down to information related to the drivers and challenges for automation of manufacturing in predefined categories. The categorization of the drivers and challenges was based on the literature and divided as either internal or external, in line with Davis et al.'s (2014) socio-technical framework. The internal drivers and challenges were categorized in terms of management system (M), technical system (T) and human system (H), in line with Dunnette and Hough's (1992) work. The external drivers and challenges were assessed in terms of regulations (R), suppliers (S), competitors (C) and customers (C*), in line with Davis et al.'s (2014) work. Besides examining the drivers and challenges for automation of manufacturing in these categories, the respondents were able to identify additional categories (A), which they perceived as being critical to consider. In the second phase of data display the data was organized in a matrix, which made it easier to draw conclusions. The final phase, which involved conclusion drawing and verification, was based on the patterns identified in the collected data as well as in relating the empirical findings to the literature.

A within-case analysis (Merriam, 2009) was performed first, where the data was analyzed individually for each case company. This step aimed at increasing familiarity and identifying the unique patterns for each case. Afterwards, a cross-case analysis (Merriam, 2009) was performed by clustering and comparisons (Miles, et al., 2019). The cross-case analysis enabled the comparison of data between the case companies that participated in the study. The findings were matched against the different predefined categories to compare them across the cases and identify patterns.

3.6 Research study D

Research study D was a systematic literature review. Employing a systematic literature review was a suitable method to build on the findings of previous research and provide a holistic perspective on the topic of interest (Jesson , et al., 2011). To obtain information from the most influential sources, research study D was limited to peer-reviewed papers in top-ranked journals within the field of operations management.

3.6.1 Structured literature search

The selection of journals was made based on searches of the databases Journal Citation Reports (JCR) by Thomson Reuters and SCimago Journal & Country Rank (SJR). The search was limited to the first quartile ranking, referring to the top 25% of ranked journals for 2015, based on the impact factor distribution the journal occupies. Duplicated results were removed. The aim and the scope of the journals were screened individually. Relevancy was defined within the scope of manufacturing systems. Journals with core emphasis on manufacturing management, manufacturing strategy and management of manufacturing technologies were defined as most relevant. In total, ten journals were selected. To confirm the relevance of the selected journals, a review of papers dealing with ranking schemes of operations management journals was performed; this resulted in an additional journal for review.

The review utilized two main search terms: “manufacturing strategy” and “automation”. Related words were identified to set the search strings, which were combined using Boolean logic. The search strings were used in each journal’s website with a couple of delimitations (Table 3.4): (1) only papers published from 2000 to 2018 and (2) only papers written in English.

Table 3.4 Literature search in research study D

Search strings	Delimitations			Sample
	Search field	Date range	Language	
“Manufacturing strategy” AND (“Automation” OR “Technology” OR “Computerization” OR “Mechanization” OR “Machinery” OR “Investment” OR “Digitalization”)	Title, abstract, keywords	2000–2018	English	192
“Manufacturing strategy”	Title	2000–2018	English	94
(“Automation” OR “Technology” OR “Computerization” OR “Mechanization” OR “Machinery” OR “Investment” OR “Digitalization”) AND (“Manufacturing” OR “Production”)	Title	2000–2018	English	218
Initial sample				504

The initial searches produced a result of 504 papers. A first screening process, which reviewed the abstracts, was performed. In this process, papers that review, describe, develop and/or evaluate manufacturing strategy frameworks were included, which resulted in 112 papers for further analysis. In the second and last screening process, a full paper review was performed. This process included papers that reviewed automation with regard to the different manufacturing strategy decision areas; this generated the final sample for the content analysis that comprised 45 papers.

3.6.2 Descriptive and content analysis

The data analysis for the systematic literature review included a descriptive analysis and a content analysis. The descriptive analysis provided a background for the content analysis through describing the formal characteristics of the literature reviewed. A Microsoft Excel sheet was created to store general information for each article (e.g., author(s), title, journal, publication year and research method). The content analysis was performed to code and interpret the collected data (Seuring & Gold, 2012). The data was condensed, coded and structured in categories, related but not limited to common manufacturing strategy decision areas (Table 2.1). Through iterative coding cycles, the data was reduced further and displayed in sub-categories. Different aspects included in each of the identified categories emerged through the coding process. Further, the various aspects in the different manufacturing strategy decision areas related to automation were revealed through comparing reviewed literature. Table 2.1 was used as a reference point to build an understanding of the scope of the different manufacturing strategy decision areas. Lastly, the data was interpreted, and conclusions were drawn regarding the specific research questions.

3.7 Research study E

Research study E was another multiple case study, one that included two real-time cases. The case study method was suitable because it enabled the investigation of a contemporary event within its real-life context (Yin, 2018) and over time. According to Mintzberg et al. (1976), to support decision-making in manufacturing system development projects, there is a need to understand events in a chronological order to determine the causal links over time. The case study method is particularly effective when conducting time-series analyses to understand events as they unfold (Yin, 2018). To gain a deeper understanding of automation decisions, two manufacturing system development projects – Project Wood and Project Wood2 – were examined. The projects were conducted at Company Main and were concerned with entirely new manufacturing plants (so-called “green factories”) stemming from new product introduction. In research study E, the manufacturing system development project was selected as the unit of analysis since investment in automation of manufacturing is commonly carried out in projects. Automation decisions in manufacturing system development projects were selected as the embedded unit of analysis.

3.7.1 Data collection

Project Wood and Project Wood2 were initiated and ongoing during the period research study E was conducted. Project Wood was initiated in February 2017 and closed in October of that year. The data related to Project Wood was collected between June and October. Project Wood2 was initiated in September 2017, and full manufacturing was running in May 2019. The data for Project Wood2 was collected between September 2017 and December 2018. The main data collection technique was participation in meetings related to the projects, primarily meetings of the project group and steering group. To collect data from the meetings, notes were taken on those aspects that were considered when making automation decisions, which decisions were made, based on what, when during the project, by who and how.

In addition to participating in meetings, data was collected through project documentation (Table 3.5). The documentation provided a basis for improving the understanding of the context of the manufacturing system development projects.

Table 3.5 Data collection in research study E

	Project Wood	Project Wood2
Participation in meetings	15	30
Documents	Project description and motivation; Project group meeting protocols; Project's activity time plan; Automation supplier quotations; Protocols from steering group meetings	Project description and motivation; Project group meeting protocols; Project's activity time plan; Automation supplier quotations; Protocols from steering group meetings

3.7.2 Data analysis

The data was analyzed following the three phases outlined by Miles et al. (2019): 1) data reduction, 2) data display and 3) conclusion drawing and verification.

In the first phase, that of data reduction, the notes taken from the meetings and documentation were reviewed. The data was then condensed down to information related to automation decisions, with an emphasis on what automation decisions are made, what is considered when the decisions are made, challenges linked to automation decisions, how these decisions are made and who makes them. Iterative coding of the data contributed with more detailed information. In the second phase, data display, the data was organized in a matrix, which made it easier to draw conclusions. The final phase, in which conclusions were drawn and verified, was based on the patterns identified in the collected data; relating the empirical findings to the literature also helped in this regard.

3.8 Research study F

Research study F was a case study that included a real-time case and a retrospective case, referred to as Project Wood2 and Project Auto in this thesis. Project Wood2 was ongoing during research study F, while Project Auto had just finished. Data was mainly collected through interviews. The chosen data collection tool allowed the investigations to be based on, but not limited to, predefined questions (Yin, 2018). This enabled flexibility in gaining an understanding of a complex topic.

In research study F, the challenges of automation decisions and the tactics that can support such decisions in manufacturing system development projects carried out in the wood products industry was studied. To gain knowledge and experiences from other industrial contexts, the research study included two development projects. Project Wood2 was conducted in the wood products industry, more specifically at Company Main. Project Auto, in contrast, was conducted in the (assumed-to-be) more mature automotive industry, more specifically, at an automotive company that manufactures trucks. Gaining understanding on how such an industry deal with automation decisions can provide valuable knowledge. Both companies were large and manufactured relatively customized products. Further, both studied projects were concerned with entirely new manufacturing plants – so-called "green factories" – that had come about due to the introduction of new products. The unit of analysis was the manufacturing system development project, with automation decisions therein selected as the embedded unit of analysis.

3.8.1 Data collection

Semi structured interviews with open-ended questions were conducted to collect data. The interviews started with questions about the aim of the project and the people involved in it. The interview continued with questions regarding decisions in the respective projects. Each interview was then narrowed down to questions on activities and decisions made related to automation, with the focus on the challenges of such decisions and how they were supported. In total, 17 face-to-face interviews were conducted, lasting between 31 minutes to 1 hour and 18 minutes. The interviews were conducted with steering group and project group members. The same interview guide was used for all respondents. Each interview was recorded and transcribed for analysis. The interviews were performed by two researchers and with each respondent individually, except for one conducted at Company Auto that involved two manufacturing representatives simultaneously. The interviews brought forward the perceptions of the people involved in automation decisions in the manufacturing system development projects. Table 3.6 displays the interview respondents that participated, the number of interviews conducted and their duration.

Table 3.6 Interviews in research study F

	Role of respondents	Number of interviews	Length of interviews
Project Wood2	Steering group representative	1	48min
	Steering group representative	1	1h
	Steering group representative	1	56min
	Steering group representative	1	31min
	Steering group representative	1	46min

	Steering group representative	1	47min
	Project manager	1	1h 06min
	Marketing and sales representative	1	1h 08min
	Marketing and sales representative	1	1h 06min
	Purchasing representative	1	50min
	Manufacturing representative	1	55min
Project Auto	Project manager	1	50min
	Finance and cost control representative	1	24min
	Manufacturing representatives	2	1h 18min
	Manufacturing representative	1	33min
	Steering group representative	1	52min

Data was also collected from each project's documentation, which provided data regarding project description and motivation, project group meeting protocols, project activity time plan, automation supplier quotations and protocols from steering group meetings. This information provided a solid basis for improving the understanding of the context of both projects.

3.8.2 Data analysis

The data was analyzed following the three phases outlined by Miles et al. (2019): 1) data reduction, 2) data display and 3) conclusion drawing and verification.

During the data reduction phase, the transcripts and notes from the interviews and documentation were reviewed. The data was then arranged in accordance with the manufacturing system design process prescribed at each company, and the data related to automation decisions was sought. In the second phase, that of data display, the data was organized in a matrix, which facilitated drawing conclusions. The third phase was based on the patterns identified in the collected data, as well the inferences drawn from relating the empirical findings to the literature.

A within-case analysis (Merriam, 2009) was performed first, with the data analyzed individually for each case company. Afterwards, a cross-case analysis (Merriam, 2009) was performed, which enabled the comparison of data between the case companies that participated in the study.

3.9 Research quality

To judge the quality of the research presented in this thesis, traditional research quality criteria were used, namely internal and external validity and reliability (Yin, 2018).

Internal validity determines whether the reported measurements comply with what the study claims to measure (Säfsten & Gustavsson, 2020) and is commonly strengthened through the application of multiple data collection techniques, also known as triangulation. Triangulation is used to check the consistency of findings. Three types of triangulation are often used (Karlsson, 2016; Torrance, 2012): (1) method triangulation, (2) source triangulation and (3) investigator triangulation. For the research studies underlying this thesis, the internal validity was increased by, among other things, planning the studies with other researchers; this helps to reduce researcher bias (Denzin, 2009). Moreover, internal validity was increased by sharing information about the research studies with the participants. Involving participants by clearly informing them about the aim of the research studies and discussing the findings with them help to reduce potential misunderstandings. Last, internal validity was further bolstered by using different forms of triangulation.

For example, in research study B, different data collection techniques were utilized, including interviews and document analysis. In addition, the collected data was of both a quantitative and qualitative character. In research study C, a multiple case study was conducted to enable comparison across cases to ensure the validity of the findings. Different data collection techniques were also used including interviews, observations and a review of documents. Research studies D and E were based on different methods and were conducted to examine the content of automation decisions. Research study D was a systematic literature review, while research study E was a multiple case study that included two real-time cases. The main advantage of real-time studies is that they do not depend on the participants that were involved in the projects to recall critical events. Moreover, different sources were used to collect data in research study E, including participating in meetings and reviewing documents. Research study F was a multiple case study that utilized various data collection techniques, including interviews and document analysis. In addition, research study F was conducted by two researchers who collected and examined the data separately and then compared perspectives. The aim of using this particular procedure was to strengthen internal validity through reducing the potential investigator bias. There were a number of other actions taken to strengthen the internal validity: before publishing scientific papers related to research studies A–C and E–F, the papers were sent to the respective contact person in each case company involved so they could have a chance to review, comments and edit information that they felt had been misunderstood by the researchers or was confidential. Furthermore, to recall data, notes were taken, and reflections were made on the observations soon after the fieldwork was made. Last, the interviews were audio recorded and transcribed; this allowed the researchers to revisit the empirical data and reduce the risk of misunderstanding (Saunders, et al., 2012; Voss, 2009).

External validity refers to the general applicability of the research findings. It is concerned with whether the findings of the research study can be applied outside the case and in other contexts (Williamson & Johanson, 2017). In case study research, limited claims can be made about the statistical generalizability of the findings since those types of studies do not involve a large set of samples due to the exploratory nature of the research. External validity in case study research should instead be established through analytical generalization (Yin, 2018). To ensure external validity, detailed descriptions of the cases including their contexts were provided. Furthermore, the research presented in this thesis compared its findings to previous research in the field. An additional way to strengthen external validity was through the presence of multiple companies from different contexts in research study C, and exploring industrial contexts outside the wood products industry in research studies D and F.

Reliability refers to the extent to which a study can be repeated by other researchers achieving the same results (Yin, 2018). To ensure reliability, the research method was described in detail. Each research study followed a systematic procedure where the collected data was documented to avoid its loss and enable transparency regarding the steps taken to answer the research questions. For the case studies, notes were taken during the progress and summaries were written shortly after the completion of each study. In addition, all of the interviews were recorded and transcribed. This practice ensured that the collected data was thoroughly documented and available for others to use. Another way to ensure reliability was by describing the data analysis method, providing other researchers with information and clear guidance on how the findings derived from the empirical data. However, despite all of this careful work one must note that the findings of a qualitative study might not always be replicable due to different circumstances. Reliability should therefore not be a measurement limited to whether the study can be replicated by others, but should rather be a measurement on whether others can see that the findings make sense given the data collected (Merriam, 2009).

4. Summary of papers

This chapter starts with an overview of the seven appended papers and continues by presenting a separate summary of each.

4.1 Overview of the appended papers

The purpose of this thesis is to support informed automation decisions in the context of manufacturing system development projects carried out in the wood products industry. The aim is to contribute with knowledge concerning the content and process of automation decisions. To fulfill the purpose and aim, four research questions (RQ1–RQ4) were formulated:

- RQ1: What are the manufacturing challenges facing the wood products industry?
- RQ2: What are the drivers and challenges for automation of manufacturing in the wood products industry?
- RQ3: What content need to be considered when automation decisions are being made in the context of manufacturing system development projects carried out in the wood products industry?
- RQ4: How can the process leading to automation decisions in the context of manufacturing system development projects carried out in the wood products industry be supported?

The research questions were addressed through seven appended papers (Papers I–VII). Figure 3.1 shows the link between the research questions and the appended papers. An overview of the manufacturing challenges in the wood products industry is provided in Paper I. The paper highlights the fact that automation of manufacturing is a challenge facing the industry, not only in connection to the process technology but also for human resources and raw material. In Paper II, the impact of the heterogenous raw material consumed in the wood products industry on the manufacturing system performance is presented. Paper II shows that the raw material has a great impact on the manufacturing system, mainly due to the material properties but there are also other factors at work. Paper III is a continuation of Paper I, focusing on the drivers and challenges for automation of manufacturing in the wood products industry. The findings of Paper III show that automation of manufacturing is viewed as a route to competitive advantage among the studied companies.

However, automation decisions were typically based on calculations of short-term financial benefits rather than being anchored to a manufacturing strategy and long-term manufacturing objectives. In Paper IV, automation decisions are examined from a manufacturing strategy perspective with emphasis on which particular aspects, in the different manufacturing strategy decision areas, need to be considered, and how, when automation decisions are being made. Paper IV emphasizes the critical importance of linking automation decisions to manufacturing strategy and highlights the need for further research in this area. While Paper IV includes experiences from other industrial sectors, in Paper V and Paper VI the aspects that are considered in the wood products industry specifically are identified. The findings presented in Paper V and Paper VI show that when automation decisions are being made, several manufacturing strategy decision areas are neglected. Furthermore, in Paper VI the process leading to automation decisions in the study context is examined. The findings show insufficient knowledge regarding automation of manufacturing and lack of structured decision-making as the main challenges. In Paper VII, automation decisions in two manufacturing system development projects, Project Wood2 and Project Auto, are examined. Project Wood2 was conducted at Company Main and Project Auto was conducted within the automotive industry. The two development projects are compared, and insights on the challenges of, and the tactics that can support, automation decisions in manufacturing system development projects are provided.

4.2 Paper I

The purpose of Paper I was to identify manufacturing challenges in the wood products industry. Paper I was based on a traditional literature review and a case study conducted at Company Main. The selected unit of analysis was the manufacturing system.

The challenges identified were categorized into the: human system, technical system, information system, material handling system, management system and others. The findings demonstrate similarities between the literature and practice in that challenges identified in both the literature and through the case study were concerned with the human system, technical system, material handling system and others. First, in the human system, competence – i.e. skills, education and experience regarding the manufacturing system – was identified as a challenge. Second, in the technical system the findings indicate underdeveloped or outdated automated solutions, limited investments and a failure to drive technology development as some of the challenges in the wood products industry. Third, in the material handling system, the challenges identified were related to the raw material; the raw material was described as bulky, which results in relatively high transportation costs. Last, the category “others” included: relatively high variations in raw material quality and relatively high material costs. The variations in the raw material placed a greater demand on manufacturing processes. Another challenge in this category was that the products are commonly customized; this is one of the reasons for the extensive use of manual labor, since increasing the levels of automation in manufacturing was perceived to limit its flexibility.

The results also included challenges that were solely identified through the case study. These issues were concerned with the human, technical, information, material handling and management systems and others. In the human system, attitudes toward change were identified as a challenge. The industry was noted to be “traditional”, a trait which cultivates a resistance to change. Regarding the technical system, the empirical findings emphasized that automation suppliers have a great impact on the development of automation of manufacturing. Limited knowledge among suppliers concerning new cutting-edge automated solutions, and the limited number of automation suppliers familiar with the specific needs of the wood products industry were identified as problems. Indeed, the suppliers were perceived to slow technology development and hinder the formation of competitive advantages. In the material handling system, material scrap was identified as a challenge. One of the reasons for the material scrap was unoptimized manufacturing flows leading to problematic internal logistics: the more the material was transported, the higher the risk of damage. Several challenges were also identified regarding the information system, for example the distribution and collection of information. The people on the shop floor perceived the distributed information as inadequate; in contrast, at the managerial level the distributed information to the shop floor was perceived to be more than was needed. Furthermore, in the managerial system, the challenges identified concerned lack of leadership skills and a vague relationship between the operational and managerial levels that led to an unsatisfied labor force. There was also an excessive focus on solving day-to-day problems rather than long-term thinking that could strengthen the company’s competitiveness. In addition, the empirical findings demonstrate challenges regarding the utilization of resources at managerial level and sharing company objectives at all levels within Company Main. In the "others" category, the empirical findings revealed that there was a fear of lagging behind competitors from low cost countries. To avoid this and keep the manufacturing in Sweden, the need to remain technologically superior to competitors from lower-cost countries was emphasized.

The challenges that were identified solely through the literature review were concerned with the human system, the management system and others. In the human system, previous literature identified the unmotivated labor force as one of the challenges the industry is facing. Regarding the management system, a challenge emphasized was quality management. Last, in the others category, several difficulties were identified: relatively low processing value added to the products, material waste and product rework, long manufacturing lead-time and limited familiarity and use of different manufacturing philosophies. A complete overview is presented in Table 4.1.

Table 4.1 Manufacturing challenges in the wood products industry

	Manufacturing challenges identified in the literature	Manufacturing challenges identified in the case study
The human system	• Insufficient knowledge • Unmotivated labor force	• Insufficient knowledge • Negative attitude to change
The technical system	• Outdated automated solutions • Lack of driving technology development • Sparse automation investments • Limited flexibility • Insufficient manner of using automated solutions	• Outdated automated solutions • Lack of driving technology development • Sparse automation investments • Limited flexibility • Insufficient manner of using automated solutions • Insufficient knowledge among the automation suppliers

		• Limited number of automation suppliers
The information system		• Distribution of information • Collection of information
The material handling system	• Bulky material • Relatively high transportation costs	• Bulky material • Relatively high transportation costs • Material scrap due to unoptimized internal logistics
The management system	• Quality management	• Lack of leadership skills • Insufficient utilization of resources at managerial level • Focus on solving daily problems • Unshared company objectives
Others	• Raw material variations • Relatively high raw material cost • Relatively high level of product customization • Relatively low value added to the products • Material waste and product rework • Relatively long manufacturing lead-time • Insufficient familiarity and use	• Raw material variations • Relatively high raw material cost • Relatively high level of product customization • Lagging behind competitors from low cost countries • Ability to keep the manufacturing system in Sweden

	of different manufacturing philosophies	

An overview of the contextual conditions of the manufacturing system in the wood products industry is provided in Paper I. The findings derived can be seen as a first step toward understanding – at least to some extent – automation of manufacturing in this industrial context.

Furthermore, in Paper I it is concluded that while some manufacturing challenges were discussed in the literature, the case study brought forward additional challenges. Paper I also shows that automation of manufacturing is part and parcel of a wide range of manufacturing problems: a clear example is seen in the connection between the relatively low levels of automation and lack of knowledge, as well as the low levels of automation and the relatively high variation of the raw material consumed. This knowledge provides decision-makers with insights on the manufacturing challenges linked to automation that need to be considered and eliminated when automation decisions in manufacturing system development projects are being made.

4.3 Paper II

The purpose of Paper II was to examine the impact of the raw material on manufacturing system performance in the wood products industry. The focus was specifically on productivity and efficiency. A case study at Company Main was conducted. The impact of the raw material was examined in terms of its direct and indirect influences. The direct influence referred to the impact of the raw material's properties on productivity and efficiency. For this reason, two wood products with different raw material properties were examined and compared (finger-joint panel and solid panel). The direct influence was determined by examining internal company documents. The indirect influence concerns the impact on productivity and efficiency from other factors related to the raw material. This was explored through interviews with, among others, the operators who were most familiar with the operational process. The unit of analysis was the manufacturing system, and as an embedded unit of analysis the impact of the raw material on the system performance was selected.

For the direct influences, quality and stop time were chosen as parameters to examine. The quality of the output gives indications regarding the efficiency since it provides information on the quantity of the manufactured products that meet quality standards. The stop time affects the processing time and thus the quantities manufactured, which, of course, provides information regarding productivity. The finger-joint panel showed a higher yield of quality A than the solid panel. Furthermore, the finger-joint panel resulted in a lower scrap rate. In addition, the finger-joint panel required less machine hours than the solid wood panel. Table 4.2 shows that the finger-jointed panel requires 7311 machine hours, whereas Table 4.3 demonstrates that the solid panel requires 7507 machine hours.

Table 4.2 Yield and total machine hours for finger-joint panel

	Yield (%)		Machine hour (rm/h)
	Quality A	Quality B	
Mean value	83.2	14.5	7311.9
Standard error	3	61.5	61.5

Table 4.3 Yield and total machine hours for solid panel

	Yield (%)		Machine hour (rm/h)
	Quality A	Quality B	
Mean value	70.7	24.7	7507.3
Standard error	1.8	1.4	112.4

The stop times organized according to the underlying reasons, for finger-joint and solid panels are shown in Figure 4.1 and Figure 4.2, respectively. The most common reason for stop time in both panels was the changeover time. However, the accumulated idle time for the finger-joint wood panel was more than double that of the solid panel. The total processing time for the finger-joint panel was 1755 minutes, while the time required to process the solid panel was 909 minutes.

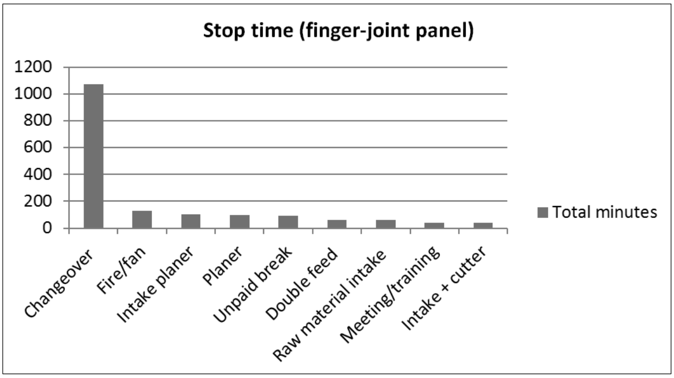

Figure 4.1 Stop time presented based on underlying reasons for finger-joint panel

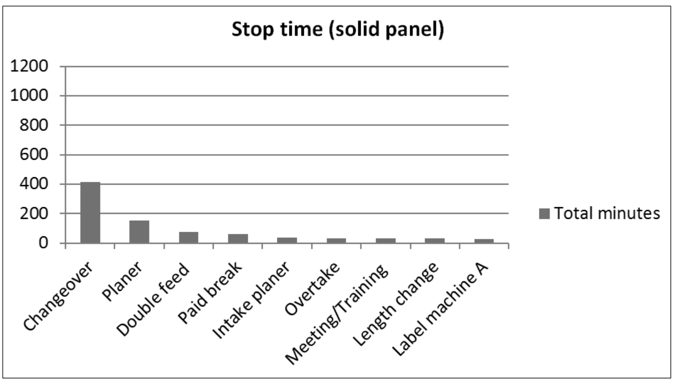

Figure 4.2 Stop time presented based on underlying reasons for solid panel

Several operational factors, such as internal manufacturing logistics, were identified as indirect influences. The transportation between inventories and the different processing stations increased the risk of material defects, which in turn increases the scrap rate. The inefficient transportation of the material was highlighted as a result of poor manufacturing flow. However, logistics was not the only reason for the increased material scrap rate; the storage of the incoming raw material in the inventories was another issue. The raw material was often bundled in large batches, and the risk of defects was increased when trucks picked up smaller batches to deliver to a different processing station. Furthermore, the machines were not perceived to be flexible enough to handle the heterogeneous materials. Therefore, a large part of the work consisted of exercising visual quality controls. In this way, the material quality, and thus the scrap rate, depended on the operators; some operators might allow the material to continue while others would scrap it.

4.4 Paper III

The purpose of Paper III was to identify the drivers and challenges for automation of manufacturing in the wood products industry. A multiple case study was carried out to explore the drivers and challenges at both operational and managerial level; it was conducted in the context of large wood products companies with manufacturing systems located in Sweden. Four companies participated in the study: Company Main, Company Windows & Doors, Company Furniture and Company Construction. The participating companies operated within different business areas – it was assumed that including multiple business areas would enable a more comprehensive view of the drivers and challenges experienced throughout the industry. The selected unit of analysis was the manufacturing system; automation of manufacturing was selected as the embedded unit of analysis.

The findings indicate a common view on the drivers for automation of manufacturing in the wood products industry (Table 4.4). Automation of manufacturing was viewed as a tool that could potentially improve productivity, result in higher quality consistency and thus increase manufacturing profitability. Automating was also expected to help companies to reduce manufacturing costs in order to remain competitive in a tough market that includes competitors from countries with far lower wage rates than Sweden. Last, an additional driver for automation of manufacturing was to increase ergonomics for the labor force.

Table 4.4 Drivers for automation of manufacturing

	Drivers	Company Main	Company Windows & Doors	Company Furniture	Company Construction
Operational level	Ergonomics	X	X	X	
	Quality consistency	X	X	X	
	Productivity		X	X	
	Meet customer demand		X	X	

	Competitiveness	X			
	Profitability		X		
	Stress reduction		X		
Managerial level	Competitiveness	X	X	X	X
	Productivity	X	X	X	X
	Profitability	X	X	X	X
	Manufacturing costs	X	X	X	X
	Quality consistency		X	X	X
	Ergonomics	X		X	X
	Labor safety	X			X
	Material utilization	X			
	Labor flexibility			X	
	Market expansion			X	
	Capacity			X	

The paper also presented some commonly identified challenges for automation of manufacturing (see Table 4.5). One of the challenges was that automation decisions were often based on gut feelings and previous experience rather than systematic analyses, which was perceived to increase risk for failure. Another challenge identified was insufficient knowledge, awareness and expertise of manufacturing system development, specifically of issues concerning automation. The low awareness of the available automation of manufacturing was described as increasing insecurities and hindering companies from making investments. Furthermore, the decided mentality of the management was identified as an additional challenge. The findings demonstrate a need for change in the direction of openness to manufacturing system development, through increased levels of automation and other measures. However, relatively high investment costs and a focus on short-term goals with the emphasis on return on investments were additional challenges facing the case companies. Further, automation of manufacturing was viewed as problematic based on the assumption that it limits manufacturing flexibility. Last, shortcomings in labor force skills and knowledge were identified as impediments to automation of manufacturing. In seeking to increase the level and complexity of automation of manufacturing, the labor force would need support through education and training.

Table 4.5 Challenges for automation of manufacturing

	Challenges	Company Main	Company Windows & Doors	Company Furniture	Company Construction
Operational level	Skills and knowledge of labor force	X	X	X	
	Manufacturing flexibility	X	X	X	
	Traditional industry	X	X		
	Technical awareness and expertise	X			
	Investment costs			X	
	Raw material	X			
Managerial level	Lack of strategies	X	X	X	X
	Short-term goals	X	X	X	X
	Investment costs	X	X	X	X
	Technical awareness and expertise	X	X	X	X
	Traditional industry	X	X	X	X
	Manufacturing flexibility		X		X
	Skills and knowledge of labor force	X			
	Raw material		X		
	Automation supplier development	X			

	Adaption to product changes		X			

Due to some unavoidable constraints, no respondents at the operational level participated from Company Construction, hence the absence of input from them in Table 4.4 and Table 4.5.

Paper III concludes that while some drivers and challenges for automation of manufacturing in the wood products industry have been discussed in the literature previously (Eliasson, 2014; NRA Sweden, 2012; Nord & Widmark, 2010), additional drivers and challenges have been brought forward by this research. Furthermore, the findings demonstrate that a distinct view on automation of manufacturing was widely shared at the managerial level in the case companies. A level of consensus was also found between the managerial and operational levels. Understanding operational needs is important for the management to form and execute successful strategic organizational decisions (Edh, et al., 2016), such as those pertaining to automation. Increased knowledge on the drivers and challenges for automation of manufacturing allows decision-makers to set clearer priorities and provides insights on the challenges that must be faced.

4.5 Paper IV

The purpose of Paper IV was to provide a holistic view on automation decisions from a manufacturing strategy perspective. The aim was to identify which aspects in the different manufacturing strategy decision areas, need to be considered, and how, when automation decisions are being made. To achieve this aim, a systematic literature review was carried out, spanning articles published between 2000 and 2018 in top-ranked international scholarly journals. The journals were in the discipline of operations management. In total, the final sample consisted of 45 articles, and a majority of the reviewed literature was based on empirical research in various industries.

The findings identify seven manufacturing strategy decision areas in operations management literature which deals with the connection between automation decisions and manufacturing strategy. These are: (1) Organization, (2) Process Technology, (3) Vertical Integration, (4) Human Resources, (5) Production Planning and Control, (6) Quality Management and (7) Facility. Some of the manufacturing strategy decision areas appeared frequently, such as human resources and organization, while others have clearly received much less attention from researchers. Three underdeveloped manufacturing strategy decision areas, regarding automation decisions that are suitable for more research were identified: quality management, facility and capacity. An overview of the findings is presented in Table 4.6. The table summarizes the manufacturing strategy decision areas connected to automation, the identified aspects considered in each and references to the papers where these aspects were found.

Table 4.6 Aspects that need to be considered when automation decisions are being made

Manufacturing strategy decision areas	Aspects in manufacturing strategy decision areas that should be considered when automation decisions are being made	References
Organization	Organizational structure – Automation can require changes regarding jobs, tasks, reporting channels and responsibilities	(Kumar, et al., 2017); (Mellor, et al., 2014); (Esan, et al., 2013); (da Rosa Cardoso, et al., 2012); (Kristiano, et al., 2012); (Farooq & O'Brien, 2009); (Fisher, 2009); (Winroth, et al., 2007); (Laosirihongthong & Dangayach, 2005); (Yen & Sheu, 2004); (Sonntag, 2003); (Das & Jayaram, 2003); (Das & Narasimhan, 2001); (Johna, et al., 2001); (Jonsson, 2000); (Cagliano & Spina, 2000); (Banerjee, 2000)
	Organizational culture – The culture, mindset and degree of familiarity in an organization can create resistance when changes	(Kumar, et al., 2017); (Mellor, et al., 2014); (Scannell, et al., 2012); (Farooq & O'Brien, 2009); (Pagell, et al., 2009);

	regarding automation are being made	(Vinodh, et al., 2009); (Lewis & Boyer, 2002)
	Organizational improvement programs – To capitalize on the competitive advantages of automation, organizational improvement programs (such as TPM) might be needed	(Jiménez, et al., 2015); (Jonsson, 2000); (Cagliano & Spina, 2000)
	Inter-functional coordination – Automation (such as CAD/CAM) can require cooperation across internal business functions	(Esan, et al., 2013)
Process Technology	Layout – Compatibility between physical layout of manufacturing and automation is required	(Winroth, et al., 2007); (Kassapoglou, 2000)
	Process compatibility – Compatibility between introduced automation and existing system is required	(Scannell, et al., 2012); (Farooq & O'Brien, 2009); (Das & Narasimhan, 2001)
	Process support – Investments in hardware can require additional investments in software	(Cagliano & Spina, 2000); (Boyer & Pagell, 2000)
	Levels of automation – Changes in the extent to which automation is implemented can have several effects on manufacturing	(Choe, et al., 2015); (Lindström & Winroth, 2010)
	Maintenance – The availability of automation is dependent on maintenance, which also involves maintenance costs	(Chan, et al., 2018); (Farooq & O'Brien, 2009); (Jonsson, 2000)
Vertical Integration	Communication in supply chain – Automation can affect the way in which	(Craighead & Laforge, 2003); (Johna, et al., 2001); (Wu & Ellis, 2000)

	information is distributed across the supply chain that aims to enable communication and learning from customers, competitors and supply partners	
	Relations in supply chain – Automation can require restructuring of relationships with supply partners to achieve desirable outcome	(Mellor, et al., 2014); (Farooq & O'Brien, 2012); (Farooq & O'Brien, 2009); (Caimon, 2009)
	Responsiveness in supply chain – Automation can affect the responsiveness in an entire supply chain network (when, for example, problems in manufacturing occur)	(Chan, et al., 2018); (Kim, et al., 2013); (Farooq & O'Brien, 2009); (Winroth, et al., 2007)
Human Resources	Physical and cognitive workload – Automation can affect the extent of physical and cognitive human labor	(Choe, et al., 2015); (Lindström & Winroth, 2010); (Jonsson, 2000)
	Skills and knowledge – Automation can require a certain level of labor force skills, knowledge and expertise	(Nujen, et al., 2018); (Kumar, et al., 2017); (Esan, et al., 2013); (Bulbul, et al., 2013); (Scannell, et al., 2012); (da Rosa Cardoso, et al., 2012); (Farooq & O'Brien, 2012); (Machuca, et al., 2011); (Farooq & O'Brien, 2009); (Fisher, 2009); (Vinodh, et al., 2009); (Caimon, 2009); (Zhou, et al., 2009); (Winroth, et al., 2007); (Laosirihongthong & Dangayach, 2005); (Das & Jayaram, 2003); (Lewis &

		Boyer, 2002); (Das & Narasimhan, 2001); (Johna, et al., 2001); (Jonsson, 2000); (Banerjee, 2000); (Kassapoglou, 2000); (Boyer & Pagell, 2000); (Li, et al., 2000)
Production Planning and Control	<u>Production planning, scheduling and control system</u> – Automation can affect the way in which production is planned, scheduled and controlled to meet customer demand	(Mellor, et al., 2014); (Winroth, et al., 2007); (Yen & Sheu, 2004); (Wu & Ellis, 2000)
	<u>Collaborative planning</u> – Automation can affect the way in which joint planning is made between different stakeholders aiming to enhance supply chain performance	(Jiménez, et al., 2015); (Winroth, et al., 2007); (Devaraj, et al., 2007); (Johna, et al., 2001); (Wu & Ellis, 2000)
Quality Management	<u>Quality control policies and practices</u> – Automation can affect the policies and practices for quality assurance in manufacturing	(Winroth, et al., 2007)
Facility	<u>Location</u> – Wage costs in the manufacturing location can affect the levels of automation chosen	(Nujen, et al., 2018); (Heikkilä, et al., 2018)

Paper IV shows that automation can impact several manufacturing strategy decision areas. However, this is also true for the impact in the other direction – that is, the impact of the different manufacturing strategy decision areas on automation implementation outcome. For example, automation of manufacturing can impact human resources since it can require a set of skills which can affect the labor force in different ways; in the opposite direction, the outcome of automation implementation can be affected by the level of skills the labor force acquires.

It is stressed in Paper IV that automation decisions can interfere with several manufacturing strategy decision areas. These need to be considered by the decision-makers when anchoring automation decisions to manufacturing strategy in order to attain the competitive advantages that may stem from automation. The findings presented in Table 4.6 can be borne in mind by decision-makers when automation decisions are being made in manufacturing system development projects. This would be a step toward helping decision-makers set appropriate requirements regarding automation of manufacturing, and when making any necessary manufacturing adjustments to support investments.

4.6 Paper V

The purpose of Paper V was to identify the aspects that are considered in practice when automation decisions are being made in the context of manufacturing system development projects carried out in the wood products industry. The findings of Paper V were based on a real-time case study that investigated automation decisions in a manufacturing system development project (Project Wood) at Company Main. The selected unit of analysis was the manufacturing system development project; the embedded unit of analysis was the automation decisions made in this context.

Project Wood was initiated at top management level with the aim to increase value-added products in the case company, and thus increase profit margins. Project Wood dealt with further processing of an existing product to increase product quality as demanded by customers. For this to happen, investments in both equipment and building were required. A project group was formed to explore the potential of and carry out Project Wood. The project group was also charged with reporting the status of the project to a steering group that was responsible for the formal decisions.

To structure the findings, the manufacturing strategy decision areas (enumerated in Table 2.1) were used. However, while the findings do indeed show that the project group did consider some manufacturing strategy decision areas when making decisions related to automation, others were neglected (see Table 4.7). Those aspects that were considered were focused on the process requirements for the automation suppliers. The discussions were concerned with manufacturing capacity, type of automation, levels of automation, manufacturing layout and the impact on existing manufacturing.

Another aspect that was frequently discussed in the project group and with the automation suppliers was the raw material. Since wood is a heterogenous material, the impact of the material variations on the product quality was considered. In addition, the impact of process technology on the material waste was also an important issue, due to increased manufacturing costs.

Table 4.7 Aspects that were considered when automation decisions were made in Project Wood

Manufacturing strategy decision areas	Considered aspects
Capacity	Manufacturing capacity
Vertical Integration	-
Facility	-
Process Technology	Type of automation Levels of automation Manufacturing layout Impact on existing manufacturing system
Quality Management	Raw material variations Raw material waste
Production Planning and Control	-
Human Resources	-
Organization	-
Others	Product specifications Perceived customer value Manufacturing costs Investment costs

The project group was then provided with proposals from the automation suppliers that were presented to the steering group. The steering group was hesitant about whether the customer would be willing to pay for the investment in the form of passed-on costs and decided therefore to change the scope of Project Wood. This resulted in an iterative process, where the project specifications changed multiple times. The focus shifted toward how to decrease the investment cost, rather than why the company wanted to proceed with Project Wood. In the end, it was decided that the project should be shut down.

Setting clear priorities and specifications for the development project early on could have prevented this situation. Furthermore, an initiative that aims to use automation of manufacturing to simply reduce manufacturing costs rarely achieves the expected outcome. This is due to the fact that automation decisions become the core strategic decision area in manufacturing; thus, automation becomes the manufacturing strategy (Winroth, et al., 2007), without considering various other aspects, such as those displayed in Paper IV. In Paper V it is set out how a great deal of focus was placed on the manufacturing strategy decision area “process technology” when automation decisions were made. This narrow focus hinders the anchoring of automation decisions to a broader manufacturing strategy perspective with long-term competitive priorities.

In Paper V, the importance of setting clear priorities and specifications for a manufacturing system development project is stressed; viewing automation decisions in the light of a broader manufacturing strategy perspective is also emphasized. Moreover, Paper V brought forward an additional aspect to consider when making automation decisions in manufacturing system development projects: the impact between automation of manufacturing technologies and raw material characteristics. This aspect is closely connected to the specific industrial context in which Project Wood was examined: the wood products industry. Furthermore, in Paper V it is concluded that automation decisions in manufacturing system development projects can be influenced by external aspects, such as the customers in this case.

4.7 Paper VI

The purpose of Paper VI was twofold: 1) explore the process leading to automation decisions in the context of manufacturing system development projects carried out in the wood products industry, and 2) identify the aspects considered when automation decisions are being made in the study context. Gaining deeper knowledge on this was assumed to support decision-makers shape improved decisions, thereby improving their ability to take advantage of the benefits connected to automation of manufacturing. The findings underlying Paper VI were based on a real-time case study examining a manufacturing system development project (Project Wood2) at Company Main. The selected unit of analysis was the manufacturing system development project and the embedded unit of analysis the automation decisions therein.

Project Wood2 was part of a bigger initiative and served as a pilot plant, aiming to increase knowledge regarding the manufacturing system before continuing with significantly greater investment in full-scale manufacturing. This was decided early on by the steering group, which was responsible for providing the broad guidelines, and was followed up during the entire project's development. This group was responsible for making the final decisions in both Project Wood2 and in relation to the full-scale manufacturing system. The steering group appointed a project group to carry out Project Wood2.

The discussions regarding automation of manufacturing were carried out in the project group together with the automation suppliers. A few automation suppliers were contacted and provided with some key information regarding the development project, such as: the layout of the building where the manufacturing system would be installed, the type of product that would be manufactured and the requested volume. The project group then asked the automation suppliers to suggest complete solutions. The decision-makers within the company were only partly aware of the details and the complexities of the different alternatives available, especially in connection to the broader and more far-reaching aspects of automation. The tendency to rely on the automation suppliers was partly driven by the company's limited willingness to acquire the knowledge to set detailed requirements for automation supporting long-term manufacturing strategy that lay outside the industry's core competence. Putting the automation suppliers in charge can have its advantages and disadvantages, as presented in Table 4.8. A related table, focused on the standard "make or buy" decision, can be found in Dranove et al. (2017).

Table 4.8 Advantages and disadvantages of reliance on automation suppliers

Advantages • Economies of scale can make the solution proposed by specialized suppliers less expensive than in-house solutions. • Market competition can force specialized suppliers to achieve higher levels of efficiency than those achievable with in-house manufacturing, and thereby enhance the cost advantage of outsourced solutions. These advantages may also involve the costs related to the certification of the equipment.
Disadvantages • General-purpose solutions can be ill-suited to match the specific needs of a company and may thus not allow the

company to take advantage of any specific opportunities that arise. • Sharing information may be leaked when an activity is performed by an independent market firm. • If drastically different solutions are available in the market, the seller can enjoy an effective monopoly position in connection with the development and the maintenance of the equipment. The supplier could exploit this position to renegotiate any previous contractual agreement, i.e. to ``hold up'' the company.

The project group then compared the alternative solutions presented by the automation suppliers, mainly in terms of: manufacturing costs (with emphasis on the number of operators required), investment costs, manufacturing capacity, previous experience and knowledge of the automation supplier, time to delivery, number of sub-suppliers involved and in terms of the alternative solutions meeting Swedish legislation and regulations governing the work environment (Table 4.9). The most promising solution, according to the project group, was then presented to the steering group. The focus of the steering group was on financial measures, while the focus of the project group was on technical solutions. The reason for that disparity could be that while the steering group included representatives from top management level, the project group mostly involved representatives from the manufacturing function.

With time, accelerating the development of the full-scale manufacturing system turned out to be so important that the company chose to proceed with it before Project Wood2 was fully developed. The reason for rushing the development project was that a competitor was starting up a plant to manufacture the same product in Sweden. Thus, the steering group for Project Wood2 was reactive rather than proactive in their decision-making.

Table 4.9 Aspects that were considered when automation decisions were made in Project Wood2

Aspects considered when automation decisions were being made
• Work environment regulations • Manufacturing layout • Manufacturing capacity • Product specifications • Levels of automation • Investment costs

- Manufacturing costs
- Previous experience and knowledge of automation suppliers
- Time to delivery of automation equipment
- Number of sub-automation suppliers involved
- Competitors' actions

The conclusion from Paper VI is that the process leading to automation decisions in the studied development project was vaguely structured: it started with briefly identifying a certain need, continued by searching for solutions through automation suppliers and finished by selecting the most promising solution. The weak point of this process was that the search for solutions was almost immediately initiated without identifying the development project's needs and goals, neither setting comprehensive specifications for automation of manufacturing. This resulted in total reliance on the automation suppliers to provide solutions based on vague requests. Furthermore, since only a few automation suppliers were contacted, the project organization based its decisions on a limited number of alternative solutions that were offered. Another weak point identified was that when the project organization for Project Wood2 was presented with alternative solutions there were insufficient and limited criteria for comparison, due to unclear and insufficient goals and specifications. Therefore, the evaluation criteria tended to rather focus on technical and financial aspects. An additional contributing factor could be that the project and steering groups included a small group of people with tightly focused perspectives. Thus, some key knowledge and perspectives might have been excluded. Furthermore, although Project Wood2 was initiated for educational purposes before investing in a full-scale manufacturing system, this aspect was ignored due to perceived pressure from competitors. Thus, automation decisions in the manufacturing system development project were influenced by external aspects, not only competitors' actions but also the previous experience and knowledge of the automation suppliers and Swedish laws and regulations of the work environment.

4.8 Paper VII

Paper VII was intended to explore the potential challenges the wood products industry is facing related to automation decisions when designing manufacturing systems and suggest tactics, with inspiration taken from another industrial sector, that can support such decisions. The findings presented in Paper VII were based on a multiple case study including Project Wood2 and Project Auto. Project Wood2 was carried out in Company Main while Project Auto was carried out in a company operating within the automotive industry. The reason for including Project Auto was to gain knowledge from an industrial sector that was presumed to be more mature with regard to investments in automation. The manufacturing system development project was the selected unit of analysis, with automation decisions within the project providing the embedded unit of analysis.

The focus was on manufacturing system design where different decisions, including automation decisions, were made prior to the implementation of the physical system. In both of the studied development projects, a project model was used to guide the development process. The project model used in Project Wood2 consisted of three phases: 1) pre-study, 2) concept development and verification followed by 3) pre-project. In Project Auto, the project model consisted of five phases: 1) background study, 2) pre-study, 3) requirements specification, 4) quotation and 5) procurement.

In each development project the following was studied in the different phases of manufacturing system design: the main activities related to automation carried out, the main automation decisions made, the challenges related to automation decisions encountered and the tactics used to support decision-making. The findings from Project Wood2 are presented in Table 4.10, while the findings from Project Auto are presented in Table 4.11.

Table 4.10 Findings from Project Wood2

	Main activities related to automation	Main automation decisions	Challenges related to automation decisions	Tactics used to support automation decisions
Pre-study	- Search for suitable automation suppliers - Gain knowledge about manufacturing system set-ups including	- Divide the development project in two sub-projects - Buy a complete manufacturing system solution including	- Lack of in-house competence regarding automated solutions - Lack of support for development of	- Increase in-house knowledge about automated solutions by starting with a pilot plant - Increase in-house knowledge

	automated solutions - Reach out to automation suppliers - Develop requirements specification for manufacturing system including automated solutions	automated solutions - Implement low levels of automation to decrease investment costs and learn by doing - Use an existing building for the new manufacturing system, including automated solutions, to decrease investment costs	requirements specification - Lack of a holistic perspective on automation when decisions were made by few people	about automated solutions by hiring an external project manager with previous experience from the automotive industry - Secure knowledge about automated solutions through automation suppliers
Development and verification	- Develop and send request for quotation to automation suppliers - Observe ongoing activities at automation suppliers through continuous discussions - Visit similar manufacturing system set-ups and view similar automated solutions - Review and evaluate the manufacturing system		- Lack of in-house competence regarding automated solutions resulting in full reliance on automation suppliers - Late involvement of purchasing function for acquirement of automated solutions - Insufficient requirements specification - Lack of documentation from	- Secure knowledge about automated solutions through automation suppliers

	concepts, including automated solutions, presented by automation suppliers - Recommend the most suitable manufacturing system concept, including automated solutions, to the steering group		previous phases - Lack of objectives for automated solutions	
Pre-project	- Select the most suitable final solution - Finalize details regarding the manufacturing system concept including automated solutions selected - Plan for realization of selected manufacturing system concept including automated solutions	- Select the most suitable automation supplier - Start with Plant2 earlier, which meant ignoring lessons to be learnt about automated solutions from pilot plant	- Scarce information	

Table 4.11 Findings from Project Auto

	Main activities related to automation	Main automation decisions	Challenges related to automation decisions	Tactics used to support automation decisions
Background study	- Explore cutting-edge automated solutions	- Implement relatively high levels of automation	- Informal process - Few people involved in decision-making resulting in lack of a holistic perspective on automated solutions	- Set clear goals for automated solutions
Pre-study	- Explore ideas on different manufacturing system concepts including automated solutions - Evaluate current and future manufacturing system including automated solutions - Conduct technology profiling to identify type of automated solutions needed - Analyze how changes in product design could	- Decided on which automated solutions to make in-house and which to buy externally - All implemented automated solutions should be tested in advance (known to the company)	- Various decisions were interdependent - Coordination between the different internal and external resources involved	- Create a multi-skilled project group following a template established at the company - Assign a project manager responsible for automated solutions - Provide template for technology profiling - Test all new automated solutions in advance

	impact the manufacturing system including automated solutions			
Requirements specification	- Develop requirements specification for manufacturing system including automated solutions			- Provide handbook supporting the development of requirements specification
Quotation	- Reach out to automation suppliers - Develop and share request for quotation with automation suppliers - Create manufacturing system concept, including automated solutions, in-house and in collaboration with automation suppliers - Review and evaluate the manufacturing system		- Coordination between the different internal and external resources involved	- Secure external competence through multiple automation suppliers - Invite automation supplier to workshop for open negotiation - Encourage collaboration between automation suppliers - Provide handbook on manufacturing standards that must be followed - Use document from the

	concepts, including automated solutions - Recommend the most suitable manufacturing system concept, including automated solutions, to the steering group			previous phases of the development process as basis to review how well different manufacturing system concepts, including automated solutions, fulfill established objectives and scope - Perform risk analysis on the different manufacturing system concepts including automated solutions
Procurement	- Select the most suitable final solution - Finalize details regarding the selected manufacturing system concept including automated solutions - Plan for realization of selected manufacturing system concept	- Select the most suitable manufacturing system concept including automated solutions		- Use checklists to ensure that agreements with automation suppliers are fulfilled during the implementation phase

	including automated solutions			

Based on the findings from Paper VII, it can safely be concluded that the project models used in the studied development projects were similar and consisted of a series of main phases which were in accordance with previous literature on manufacturing system design (Bellgran & Säfsten, 2010): background study, pre-study, concept study, evaluation and detailed design. Figure 4.3 provides a comparison between the project models studied here and a general development process for manufacturing system design presented in the literature (Figure 2.2).

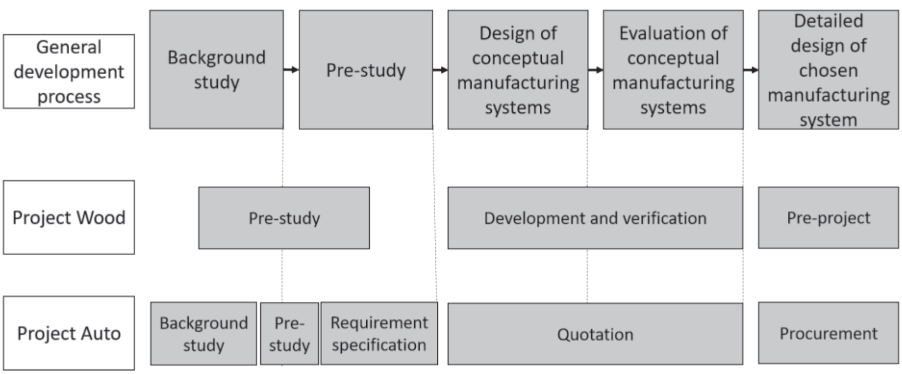

Figure 4.3 The development process

Moreover, it can be concluded that the formidable challenges related to automation decisions during the manufacturing system design in Project Wood2 were connected to a lack of recognition of the strategic relevance of automation of manufacturing, lack of competence regarding automation of manufacturing and lack of structured approaches supporting automation decisions in the development process. These challenges could potentially be mitigated by the early establishment of objectives for automation of manufacturing, strengthening in-house expertise related to automation, involving different departments within the company to secure various – and varied – perspectives when automation decisions are being made, and finally by recognizing the presence and relevance of established routines supporting the decisional process.

5. Discussion

In this chapter, the main findings from the research are discussed in relation to the previous literature. The chapter is divided into four main sections; each section deals with one of the four research questions proposed in this thesis.

5.1 Manufacturing challenges in the wood products industry

In this section, manufacturing challenges in the wood products industry are discussed, with the focus on RQ1:

- RQ1: What are the manufacturing challenges facing the wood products industry?

The discussion is based on the findings from research studies A and B, presented in Papers I and II. In research study A, presented in Paper I, general manufacturing challenges in the wood products industry were identified. The findings were based on a single case study conducted at Company Main and a traditional literature review. To gain a holistic perspective, a system approach was applied. The identified manufacturing challenges were categorized as belonging to the human system, technical system, information system, material handling system, management system and others (Table 4.1).

Some of the manufacturing challenges were identified both empirically and in the traditional literature review. One such challenge was insufficient knowledge among the labor force. It was emphasized as a result of low education levels, along with missing certificates and operation licenses (Teischinger, 2010; Wiedenbeck & Parsons, 2010). This challenge is not specific to the wood products industry but is commonly reported in several different industrial sectors (Nujen, et al., 2018). In order to overcome this challenge, previous literature emphasizes the critical role of training and up-skilling (Kumar, et al., 2017). Another identified challenge was the utilization of outdated automated solutions in the wood products industry. This was associated with sparse investments and a failure to drive technology development. Previous researchers have emphasized a need for investments in new and efficient automation of manufacturing in order to maintain or increase the competitive advantages of the wood products industry (Makkonen, 2018; NRA Sweden, 2012). An additional identified challenge was the inefficient manner of using automated solutions, which was resulting in a decline in manufacturing productivity (DeLong , et al., 2007; Mital & Pennathur, 2004). This problem has been found in other industrial contexts as well, often in labor-intense and small and medium sized (SME) companies (Charoenrat & Harvie, 2013); these characteristics tend to predominate in the wood products industry (Landscheidt & Kans, 2016). Moreover, lack of flexibility was identified as an additional manufacturing challenge in the wood products industry (Kozak & Maness, 2003). This was likewise emphasized by the respondents from Company Main, who articulated a concern regarding automation of manufacturing limiting the flexibility needed to manufacture products with a relatively high level of customization (described as frequently requested from customers within the industry). This is a common concern that can be found in other industrial sectors considering investments in the automation of manufacturing (Díaz-Reza, et al., 2019).

Further manufacturing challenges addressed in the traditional literature review and identified empirically were related to the raw material consumed in the wood products industry. For example, the relatively high variations in the heterogeneous character of the raw material often result in waste and product rework (Eliasson, 2014; Kozak & Maness, 2003; Radovan, et al., 2001). Kozak and Maness (2003) emphasize different reasons for the raw material variations: knots and other natural defects, splits, cracks and variable moisture content. Karltun (2007) states that these variations pose difficulties since they influence automation of manufacturing in terms of the processing speed and cutting forces. Such heterogeneity is believed to be one of the main reasons why wood products companies have low levels of automation (Karltun, 2007). The challenge of the raw material variations was also identified in research study B, presented in Paper II, that examines the impact of the raw material on the manufacturing system performance. An additional challenge related to the raw material was the relatively high costs of it. Furthermore, because of its bulk, the raw material was difficult to handle, and this meant relatively high transportation costs. The challenges which emerged regarding the raw material are specific to the wood products industry.

Some of the manufacturing challenges were identified solely empirically and were not addressed in the traditional literature review conducted in research study A. One such challenge was the negative attitude to change that prevails in the industry. The respondents from Company Main described the wood products industry as a traditional, with a distinct culture that features a strong established perception of its mission, the boundaries of its activity and its routines. The prevailing culture was perceived as linked to resistance to change. Resistance to change linked to, for instance, investments in automation of manufacturing is commonly addressed in previous literature dealing with different industrial sectors (Mellor, et al., 2014). The role of adequate training for the workforce is often emphasized as critical to tackle this challenge (Kumar, et al., 2017).

Another challenge that was identified solely through empirical work in research study A was the sparse number of automation suppliers capable of fully understanding the manufacturing needs of the wood products industry. This shortcoming in knowledge is notably specific to the wood products industry. An additional empirically identified challenge was that the processes were not integrated – this was perceived as an obstacle to the optimization of the manufacturing system. The difficulties of process integration can be identified in other industrial contexts as well (Atkins, et al., 2010).

Moreover, both the distribution and collection of information were identified as difficult at the operational and managerial levels at Company Main. The operational level emphasized that the distribution of information – also the type and amount of information – on the shop floor was perceived as inadequate. Unlike the operational level, the managerial level described an overflow of information distribution. However, the managerial level emphasized the collection of information as a challenge. It was clear that there was a need for further communication between the operational and managerial level regarding the type and amount of information needed. No challenges regarding the information system were identified in the traditional literature review conducted in research study A. This might be due to the exclusion of literature addressing this issue, inadequate research within the research area or the very specific challenges faced by the company studied here.

Further issues identified empirically and not addressed in the traditional literature review were concerned with lack of leadership skills, a lack of long-term objectives that are communicated at the manufacturing company, the focus on solving daily problems and insufficient utilization of resources at managerial level. These are dealt with in some previous literature (covering different industries) that emphasizes the need for improvement since the role of leadership skills and clearly communicated strategic objectives are critical for organizational performance (Ramere & Laseinde, 2020; Monye & Ibegbulem, 2018). Another empirically identified challenge was the fear of lagging behind competitors from low-cost countries, a threat which if realized might lead to a situation where the manufacturing system(s) could not be kept in Sweden. Losing manufacturing systems to low labor cost countries is a concern which has been dealt with more and more in recent literature analyzing different industries (Pal, et al., 2018).

Last, some manufacturing challenges were only identified through the traditional literature review, notably the notion of the unmotivated labor force. This is a challenge that is faced in other industries, and previous literature emphasizes the critical role of this issue on organizational performance (Varma, 2018). This topic is gaining popularity among researchers examining the wood products industry; there are now various studies aiming to support the industry to deal with this challenge by increasing the understanding of what motivates the labor force (Hitka, et al., 2020; Faletar, et al., 2016). Other manufacturing challenges solely identified in the literature review were concerned with quality management, low value added to the products manufactured, long manufacturing lead-times and low familiarity with and use of manufacturing philosophies. All of these difficult issues have been acknowledged in previous literature that studied various industries (Zaidin, et al., 2018; Strandhagen, et al., 2018; Salem, et al., 2016).

To sum up, the findings show that many of the identified manufacturing challenges can be found elsewhere by comparing with research studies that looked at other industrial contexts. However, the findings demonstrate that some of the issues that came to light are specific to the wood products industry. Moreover, this research has – through empirical studies – identified some manufacturing challenges that are additional to those previously reported in literature dealing with the wood products industry. Last, this research shows that various manufacturing challenges in the wood products industry were connected to automation of manufacturing: for example, lack of sufficient knowledge and ingrained resistance to change are two contributing factors to lack of investments in automation of manufacturing, resulting in outdated and inefficient manufacturing systems.

5.2 Drivers and challenges for automation of manufacturing in the wood products industry

In this section, automation of manufacturing in the wood products industry is discussed in relation to RQ2:

- RQ2: What are the drivers and challenges for automation of manufacturing in the wood products industry?

The discussion is based on the findings from research study C, presented in Paper III. A multiple case study was conducted at different wood products companies. The drivers and challenges for automation of manufacturing in the wood products industry were identified (see Table 4.4 and Table 4.5). The drivers refer to what motivates wood products companies to invest in automation of manufacturing. The identified drivers for automation of manufacturing were related to, inter alia, the labor force, especially reduced labor stress, improved ergonomics and increased labor flexibility and safety. Some of the identified drivers for automation of manufacturing were of a strategic character. Examples of such drivers were: the desire to expand in the market, increased quality consistency, increased capacity and increased competitiveness. Other identified drivers for automation of manufacturing were meeting customer demand, increased productivity, increased material utilization, increased profitability and decreased manufactruing costs, such as labor costs.

Previous literature on the drivers for automation of manufacturing in the wood products industry has tended to focus on drivers related to technical or financial measures. For example, Sandberg et al. (2014) stress improved productivity, Korhonen-Sande and Niemelä (2005) and DeLong et al. (2007) emphasize increased technical efficiency and Eliasson (2014) and Karltun (2007) discuss decreased manufacturing costs. This narrow focus might exclude some relevant drivers for automation of manufacturing, such as those connected to the labor force, as identified in research study C and presented in Paper III.

When comparing the drivers for automation of manufacturing in the wood products industry to other industrial sectors, similarities can be found. A number of studies show that acquisition of automation of manufacturing is commonly driven by the need for increased productivity and cost competitiveness (Ratnasingam, et al., 2020; Paritala, et al., 2017; Cimini, et al., 2017). Groover (2015) extends the view on drivers and describes how in general investment in automation of manufacturing initiated from the management level tends to prioritize: increased labor productivity, reduced labor costs, improved product quality and reduced manufacturing lead-time. In contrast, investment in automation of manufacturing initiated from the shop floor level focuses on reduced manual tasks and improved labor force safety. The empirical findings from research study C, presented in Paper III, indicate that a consensus of the drivers for automation of manufacturing was found between the managerial and operational levels. This consensus is favorable since understanding operational needs is important for the management to form successful strategic organizational decisions (Edh, et al., 2016), such as automation decisions.

The findings indicate associations between the identified drivers for automation of manufacturing and the manufacturing challenges found in the wood products industry. For example, an association is found between the drive to reduce labor stress, improve ergonomics, increase labor safety and labor flexibility and the challenge related to the tough work environment described in the wood products industry. Moreover, the findings indicate an association between the drive to automate in manufacturing in order to increase profitability and the challenge related to the low manufacturing value added to the products resulting in small profit margins. The drive to increase quality consistency and material utilization appears to have an association with the challenge regarding the raw material variations which commonly result in material waste and product rework. An association is indicated between the drive to meet customer demand, increase productivity and capacity and the challenge related to the technical inefficiency in addition to long manufacturing lead-times and outdated automation of manufacturing used in the industry. Last, a link is indicated between the drive to increase competitiveness and decrease manufacturing costs due to the fear of lagging behind low-cost labor countries. The drivers for automation of manufacturing and their probable association with the manufacturing challenges are presented in Table 5.1.

Table 5.1 Drivers for automation of manufacturing and their association to different manufacturing challenges in the wood products industry

Drivers for automation	Manufacturing challenges
• Reduce labor stress • Improve ergonomics • Increase labor safety • Increase labor flexibility	• Tough work environment
• Increase profitability	• Low manufacturing value added to the products
• Increase quality consistency • Increase material utilization	• Raw material variations
• Increase productivity • Increase capacity • Meet customer demand	• Technical inefficiency • Long manufacturing lead-times • Outdated automation of manufacturing
• Increase competitiveness • Decrease manufacturing costs	• Lagging behind low labor cost countries

In contrast to the drivers, the challenges refer to those things which hinder automation of manufacturing. A greater understanding of these challenges was assumed to provide insights for the decision-makers on what to consider when automation of manufacturing is contemplated. Some of the identified challenges for automation of manufacturing can be found in other industries, as addressed in previous literature. The joint challenges shared by different industrial sectors were:

- Insufficient skills and knowledge among the labor force
- Relatively high investment costs
- Lack of strategies, and short-term goals
- Insufficient technical awareness and expertise
- Lack of manufacturing flexibility
- Resistance to change

The low skills and knowledge levels of the labor force form a common challenge for automation of manufacturing that is apparent in several industrial sectors (Kumar, et al., 2017; Esan, et al., 2013). In order to handle the implementation of more complex automated solutions in manufacturing sufficiently, certain skills and knowledge of the labor force are often required (Nujen, et al., 2018); indeed it is emphasized as an essential component if the full benefits of investments in automation of manufacturing are to be utilized (Kumar, et al., 2017). Furthermore, the relatively high investment costs are yet another challenge for automation of manufacturing that faces various industries (Fette, et al., 2016). However, focusing on financial justifications when making automation decisions can result in short-term goals and a tendency to solve only day-to-day problems, leading to neglect of long-term strategies (Chan, et al., 2001). Previous literature, dealing with different industrial sectors, stresses the importance of systematically anchoring automation decisions to long-term strategies in order to achieve the optimal manufacturing performance (Machuca, et al., 2011; Jiménez, et al., 2011; Farooq & O'Brien, 2009). Moreover, the insufficient technical awareness and expertise for automation of manufacturing in-house was a challenge that was identified by a number of the wood products companies that participated in research study C. It was said to be due to limited R&D activities, resulting in firms relying on external competencies; this is also discussed in relation to other industrial sectors (Grimpe & Kaiser, 2010). Additional identified challenges for automation of manufacturing that can be found across different industrial sectors were sustaining manufacturing flexibility and tackling resistance to change. When implementing automation of manufacturing, several conflicts can occur. One such conflict is related to the balance between the levels of automation chosen and the manufacturing flexibility required (Wiktorsson, et al., 2017). Another conflict concerns the degree of resistance to change, a challenge that was also identified in research study A, presented in Paper I. This resistance was described as associated with the traditional nature of doing things as they have always been done in the wood products industry. Resistance to change has been addressed in other industries, and tackling it is seen as important in order to utilize the full array of benefits related to the automation of manufacturing (Farooq & O'Brien, 2012).

Other identified challenges for automation of manufacturing in research study C, presented in Paper III, are probably more specific to the wood products industry. One such challenge is that presented by raw material variations. This was also identified in research study A, presented in Paper I. Deeper understanding of the implications of the raw material variations on automation of manufacturing was developed through research study B, presented in Paper II. The findings indicate that the characteristics and variations in the raw material impact several aspects of the manufacturing system. Not considering this when making automation decisions can result in different implications for the investment. For example, if the nature of the raw material is not considered when automation decisions are made, it might result in a higher degree of scrap and thus increased manufacturing costs. Another specific challenge was the lack of automation suppliers' understanding of the wood product industry's needs. This was perceived as a factor limiting developments regarding automation of manufacturing in the wood products industry. This challenge was also identified in research study A, presented in Paper I.

5.3 The content of automation decisions

In this section, the content of automation decisions is discussed. The issue is addressed by RQ3:

- RQ3: What content need to be considered when automation decisions are being made in the context of manufacturing system development projects carried out in the wood products industry?

Content refers to the aspects that need considerations when automation decisions are being made. The discussion is based on the findings derived from research study D and E, presented in Papers IV–VI. In research study D, the aspects in the different manufacturing strategy decision areas, that need to be considered when automation decisions are being made, were identified (Paper IV). Previous studies show that investments in automation of manufacturing are more likely to succeed if they are anchored to a manufacturing strategy (Garrido-Vega, et al., 2015; Liu, 2013; Machuca, et al., 2011; Jiménez, et al., 2011), and therefore the manufacturing strategy perspective was selected.

When automation decisions are being made there is a need to go beyond the manufacturing strategy decision area of process technology in order to capitalize on the potential advantages for automation of manufacturing (Machuca, et al., 2011). Changes in one manufacturing strategy decision area, such as process technology, might require changes in other areas to attain the expected benefits. Thus, it follows that making decisions regarding one decision area might require the decision-maker to consider other areas. For example, when investing in automation the manufacturing strategy decision area human resources needs to be considered with regard to, for example, required skills (Kumar, et al., 2017). Different authors pinpoint different aspects in various manufacturing strategy decision areas to consider when making automation decisions. Mellor et al. (2014) stress organizational culture as just such an aspect, Scannell et al. (2012) mention process compatibility and Caimon (2009) stresses the impact of relationships with supply partners. To provide a holistic view of previous studies, a systematic literature review was conducted. The articles in the systematic literature review covered various industries.

The findings demonstrate that the following seven manufacturing strategy decision areas need to be considered when automation decisions are being made: (1) Organization, (2) Process Technology, (3) Vertical Integration, (4) Human Resources, (5) Production Planning and Control, (6) Quality Management and (7) Facility. In each of these areas, several aspects related to automation were identified (see Table 4.6). In the decision area organization, organizational structure (Kumar, et al., 2017), organizational culture (Mellor, et al., 2014), organization improvement programs (Jiménez, et al., 2015) and inter-functional coordination were identified (Esan, et al., 2013). In the decision area process technology, layout (Winroth, et al., 2007), process compatibility (Scannell, et al., 2012), process support (Cagliano & Spina, 2000), levels of automation (Choe, et al., 2015) and maintenance (Chan, et al., 2018) were identified. In the decision area vertical integration, communications in supply chains (Craighead & Laforge, 2003), relations in supply chains (Mellor, et al., 2014) and responsiveness in supply chains (Chan, et al., 2018) were identified. In the decision are human resources, skills and knowledge (Nujen, et al., 2018) and physical and cognitive workload (Choe, et al., 2015) were identified. In the decision area production planning and control, production planning, scheduling and control system (Mellor, et al., 2014) and collaborative planning in supply chains (Jiménez, et al., 2015) were identified. In the decision area quality management quality, control policies and practices (Winroth, et al., 2007) were brought to the fore. Last, in the decision area facility, location (Nujen, et al., 2018) was identified.

While most of the aspects identified were internal to manufacturing companies, collaborative planning in the decision area production planning and control as well as relations in supply chains, communication in supply chains and responsiveness in supply chains (which were identified in the decision area vertical integration) were all external aspects. The results of the systematic literature review further show that while some manufacturing strategy decision areas were frequently considered, others were less considered, if at all. The most notable manufacturing strategy decision area was human resources, followed by organization. Quality management and facility received less attention; in facility specifically, location was identified. Automation of manufacturing was emphasized as a tool used in order to bring manufacturing back to high-cost locations, such as Western countries. This is the case since automation of manufacturing was assumed to decrease costs related to wages (Heikkilä, et al., 2018). Location has been emphasized by recent studies, which indicates an interest in studying automation of manufacturing in the context of reversed outsourcing (Nujen, et al., 2018). Capacity was not discussed in relation to automation decisions in the reviewed literature despite it being a key manufacturing strategy decision area (Slack & Lewis, 2019; Miltenburg, 2005).

In research study E, the aspects that are considered in practice when automation decisions are being made in the context of manufacturing system development projects conducted in the wood products industry were identified. Two manufacturing system development projects, Project Wood and Project Wood2, at Company Main were studied. The findings derived from Project Wood were presented in Paper V, while the findings derived from Project Wood2 were presented in Paper VI. In general, the findings demonstrate that when automation decisions were made, different aspects were considered. Among the things considered were manufacturing layout, type of automation and levels of automation. These considerations are closely connected to the manufacturing strategy decision area process technology. Additional aspects of importance were the raw material variations and raw material waste, which are linked to the decision area quality management. Moreover, manufacturing capacity was an aspect which is linked to the decision area capacity. Other identified aspects were product specifications, manufacturing costs and investment costs; these did not fit in any of the manufacturing strategy decision areas and were categorized as "others".

The findings are in line with previous studies that emphasize different internal aspects of companies that should be considered in order to support the evaluation and selection regarding automation of manufacturing (Almannai, et al., 2008; Shehabuddeen, et al., 2006). In addition to internal company aspects, Shehabuddeen et al. (2006) emphasize the importance of considering external aspects in decision-making regarding automation of manufacturing. These external aspects are described as related to customers, automation suppliers, competitors and regulatory bodies. This logic provides a holistic understanding, including the internal company perspective as well as the wider business environment.

Multiple aspects that were identfied in research study E could be categorized in a similar way. For example, in Project Wood the customers' willingness to pay for costs related to further manufacturing processing of the final product – clearly an external aspect was considered. The goal of Project Wood was to add additional manufacturing processing value to an existing product in order to increase its quality. However, later in the manufacturing system development project, the steering group doubted if customers would be willing to pay for the additional manufacturing costs. The strategic objectives of the manufacturing system development project were deprioritized as the focus was on decreasing the investment costs. An additional external aspect was competitors' actions. A similar situation to Project Wood occurred in Project Wood2, where the strategic objectives of the manufacturing system development project were deprioritized. In Project Wood2, one of the milestones was to start by investing in a smaller plant. The aim was to increase knowledge and familiarity with the manufacturing system that was new to the company, before proceeding with significant investment in full-scale manufacturing. However, later in the development project this milestone was deprioritized due to external pressure from competitors in terms of time-to-market. These two examples show that the strategic objectives related to investments in automation of manufacturing were clearly neglected. Besides the customers' anticipated response and competitors' actions, other external aspects were considered: previous experience and knowledge of the automation suppliers, number of sub-suppliers, the automation suppliers' estimated time to delivery and work environment regulations. Figure 5.1 summarizes the internal and external aspects and sets out the full content of automation decisions identified in the research studies presented in this thesis.

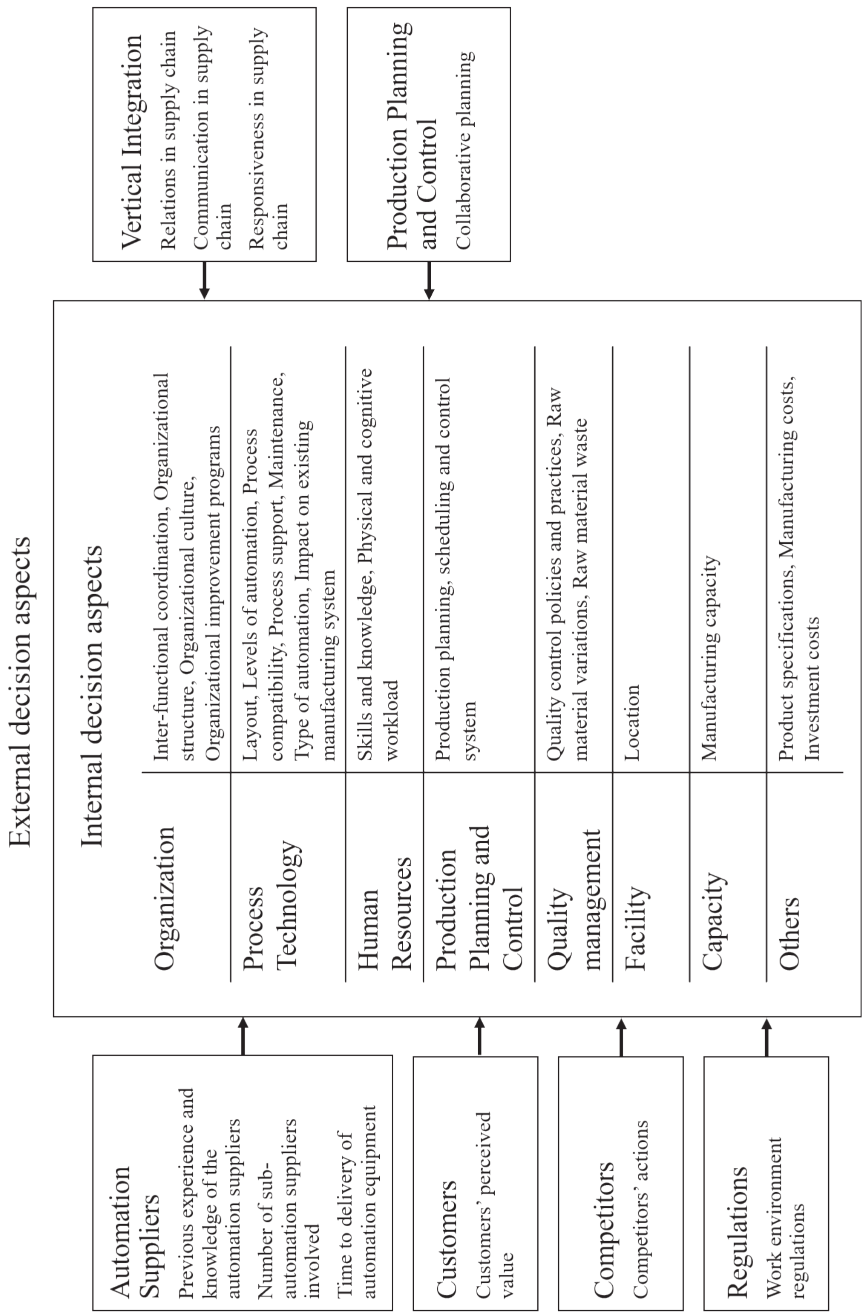

Figure 5.1 The content of automation decisions

In relation to the findings from the systematic literature review stemming from research study D, the empirical findings derived from research study E indicate that several manufacturing strategy decision areas were also neglected in practice. When automation decisions were made, emphasis was placed on the manufacturing strategy decision area process technology, which is in accordance with previous literature (Winroth, et al., 2007). Some aspects in the manufacturing strategy decision areas human resources, capacity and quality management were considered in the studied manufacturing system development projects. However, aspects linked to the manufacturing strategy decision areas vertical integration, facility, production planning and control and organization were neglected.

To sum up, the empirical findings derived from research study E indicate that from a manufacturing strategy point of view various aspects in different decision areas were not considered when automation decisions in manufacturing system development projects were being made in practice. Second, the empirical findings demonstrate that although strategic aspects were set in the manufacturing system development projects studied, they were neglected. This is line with the findings from research study C, presented in Paper III, that emphasize lack of strategies as a challenge for automation of manufacturing in the wood products industry. Third, the empirical findings indicate that besides internal aspects, external aspects emanating from customers, automation suppliers, competitors and regulations can influence automation decisions. Fourth, the empirical findings show that several drivers and challenges for automation of manufacturing in the wood products industry, identified in research studies A–C and presented in Papers I–III, were neglected when making automation decisions: examples are ergonomics, labor safety and labor skills.

5.4 The process of automation decisions

In this section, the process of making automation decisions is discussed; RQ4 deals with this:

- RQ4: How can the process leading to automation decisions in the context of manufacturing system development projects carried out in the wood products industry be supported?

The process refers to the different steps and actions that are taken leading ultimately to automation decisions. The discussion is based on the findings which emerged from research studies E and F, presented in Papers VI and VII. In research study E, a manufacturing system development project, Project Wood2, carried out at Company Main was studied. The focus was on gaining knowledge about the process leading to automation decisions in the manufacturing system development project prior to the implementation of the physical system. In research study F, two manufacturing system development projects, Project Wood2 and Project Auto, were included. Automation decisions were studied in the different phases of manufacturing system design. The intention was to explore the potential challenges which the wood products industry is facing related to automation decisions when designing manufacturing systems; the aim was also to suggest tactics, with inspiration from another industrial sector, that can support such decisions. Project Auto was carried out in the automotive industry, assumed to be a more mature industry with regard to investments in automation of manufacturing.

A project model was used in each of the development projects studied, in an attempt to guide the development process during manufacturing system design. The project models in Project Wood2 and Project Auto included some similar phases with related activities. These were in accordance with previous literature that divides the manufacturing system design process into five phases (Bellgran & Säfsten, 2010): background study, pre-study, concept study, evaluation and detailed design.

Different challenges were encountered related to automation decisions in the different phases of the development process. One of the challenges encountered in both development projects during the background study phase was the lack of a holistic perspective when automation decisions were made. The main reason for this was that at this stage only a few people from the management level were involved in decision-making. This can be a disadvantage according to prior research that stresses the importance of including various perspectives when considering investments in the automation of manufacturing (Winroth, et al., 2007). One way to deal with this challenge in Project Auto was through creating a multi-skilled project organization during the pre-study phase. This was done with support from an established template which the company used for large manufacturing system development projects.

Moreover, in Project Wood2, poor support for the development of requirements specification was stressed during the pre-study phase. Requirements specification is vital as it guides the manufacturing system design process and the evaluation of the system on a conceptual as well as a detailed level (Bruch, et al., 2009). Therefore, requirements specification that are well formulated and detailed are emphasized to be of great importance for a successful outcome (Granlund & Friedler, 2012). A need to support the development of requirements specification was identified; this could be done through working in a structured manner, as was done in Project Auto, by providing for example handbooks and templates.

Among the main challenges in Project Wood2 that were emphasized during the background study, pre-study and design of conceptual manufacturing systems phases was the lack of in-house competence regarding automation of manufacturing. This is in line with previous research that describes lack of competence as a prevalent challenge in the wood products industry, characterized as it is by low education levels among the workforce (Ratnasingam, 2015; Teischinger, 2010). Companies operating in the wood products industry are struggling to meet their growth prospects (Kozak, 2005). Insufficient skills and knowledge are highlighted as one of the biggest impediments (DeLong , et al., 2007). Stendahl and Roos (2008) stress that inadequate staffing and the low educational level of white-collar workers frequently hampers the development activities of wood products companies. The struggle of finding the right competence levels might well continue in the future: members of the young generation who do have the relevant education find the wood products industry unattractive in career terms (Träregion Småland , 2014). Therefore, companies operating in this industrial sector might need to consider how to become an attractive employer. This might be something to consider in other industries as well, since a lack of basic competence is not specific to the wood products industry but is apparent in different industrial sectors when investments in automation of manufacturing is discussed (Nujen, et al., 2018).

The findings indicate that when competence in relation to automation of manufacturing in a company is limited, it results in uncertain preferences. The decision-makers tend to heavily rely on the automation suppliers to provide complete solutions based on vague requests, rather than developing the company's own internal competence portfolio. 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). Furthermore, when companies put automation suppliers effectively in charge, they are often offered standardized solutions that are available to competitors. This was a specific concern that was expressed in Project Wood2. The findings also showed that in Project Wood2 only a few automation suppliers were contacted, in marked contrast to Project Auto. Accessing a broader spectrum of automation suppliers can be important to gain relevant technological knowledge (Kang, et al., 2015).

To deal with the lack of in-house competence regarding automation of manufacturing there is need to invest in human resources. In Project Auto, a project manager was assigned responsibility for automated solutions specifically. An additional way to deal with an absence of in-house competence is through testing all automated solutions that are new to the company in advance of the implementation of the new manufacturing system; this was decided upon in both studied development projects early in the development process. By doing this, decision-makers can make more informed decisions and operators can train prior to 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 papers that looked at different industries) also indicates that training is critical in order to utilize the full benefits of investments in automation of manufacturing (Helu, et al., 2015).

Another challenge stressed in Project Wood2 was the scarcity of relevant information. This was pointed out during the evaluation of conceptual manufacturing systems and the detailed design of the chosen manufacturing system. When the project organization for Project Wood2 was presented with alternative solutions there was insufficient and limited criteria for comparison, due to unclear and insufficient goals and specifications. The scarce information was also described as a result of, *inter alia*, lack of documentation from previous phases during manufacturing system design. In general, the process leading to automation decisions was vaguely structured in Project Wood2. The search for solutions was initiated almost immediately, without setting objectives and comprehensive specifications for the automation of manufacturing. The absence of clear objectives and the insufficient requirements specification might be a direct result of the lack of in-house competence in the company.

To support the process leading to automation decisions, the findings show, suggest a need to strengthen knowledge on automation of manufacturing in the project organization. For the right competences to be included, in-house capacity generated through investment in human resources is required. In addition, to ensure that various perspectives are involved in the manufacturing system development project, a multi-skilled project group could have been created. This strategy was adopted early in Project Auto with the support of an established template used for large development projects in the company. This is one example of where Project Auto used structured approaches to support decision-making. On a related note, working in a more structured manner would be generally more beneficial. Through a structured decision-making process postulated in rational decision-making discipline can effectively be imposed on the decision-makers, for example via the use of templates and manuals. This was certainly seen in Project Auto, where different activities were conducted, and templates and handbooks were used to support the evaluation process. Last, the findings show that to support the process leading to automation decisions, there is a need to recognize and establish the strategic relevance for automated solutions early in the development process. In contrast to Project Wood, in Project Auto automation had a strategic role which was established early during the manufacturing system design. Frohm (2008) points out that one of the main reasons why automation investment projects fail is due to undefined objectives. Thus, companies should recognize that the strategic relevance of automation justifies a comprehensive approach to its implementation. Table 5.2 summarizes the potential challenges related to automation decisions that face the wood products industry during manufacturing system design, and also lists some of the tactics that can be used to support such decisions.

Table 5.2 Some challenges related to, and tactics that can support, automation decisions when designing manufacturing systems in the wood products industry

	Potential challenges related to automation decisions	Tactics that can be used to support automation decisions
Background study	- Lack of in-house competence regarding automation of manufacturing - Lack of holistic perspective on automation when decisions were made by few people	Invest in human resources Test all new automated solutions prior to the implementation of the new manufacturing system Create multi-skilled project group Recognize and establish the objectives for automation of manufacturing
Pre-study	- Lack of in-house competence regarding automation of manufacturing - Lack of support for development of requirements specification	- Invest in human resources - Impose structured approaches and discipline by use of, for example, templates and manuals
Design of conceptual manufacturing systems	- Lack of in-house competence regarding automation of manufacturing resulting in over-reliance on automation suppliers	- Invest in human resources - Impose structured approaches and discipline by use of, for example, templates and manuals - Access a broader spectrum of external automation solutions providers

Evaluation of conceptual manufacturing systems	- Scarce information	- Impose structured approaches and discipline by use of, for example, templates and manuals
Detailed design of chosen manufacturing system	- Scarce information	- Impose structured approaches and discipline by use of, for example, templates and manuals

6. Conclusions

This chapter presents the conclusions drawn from the research. Additionally, the theoretical and industrial contributions made by the work are outlined, followed by a presentation of the limitations of the underlying studies together with recommendations for future research.

6.1 Answering the research questions

Investments in new and efficient automation of manufacturing are recognized as significant determinants for sustained manufacturing competitiveness in the wood products industry (Makkonen, 2018; NRA Sweden, 2012). To ensure fulfillment of the potential competitive advantages when investing in automation of manufacturing, the literature emphasizes the importance of well-grounded automation decisions. However, a problem inherent to automation decisions is that they are often made ad hoc and based on gut feelings (Lindström & Winroth, 2010). There is a need to understand what should be considered and how the process should be structured when automation decisions are being made in the context of manufacturing system development projects taking place in the wood products industry. Therefore, the ultimate purpose of this thesis was to support informed automation decisions in the context of manufacturing system development projects carried out in the wood products industry. To fulfill this purpose, four research questions (RQ1–RQ4) were addressed. Presented below are the conclusions drawn in relation to the research questions.

RQ1: What are the manufacturing challenges facing the wood products industry?
Based on the findings presented in this thesis, it can be concluded that manufacturing companies in the wood products industry are facing various challenges affecting their competitiveness. These challenges have been categorized as follows, into: 1) the human system, 2) the technical system, 3) the information system, 4) the material handling system, 5) the management system and 6) others. In the human system, the challenges involved insufficient knowledge, an unmotivated labor force and negative attitudes to change. In the technical system, the difficulties were extensive, involving the

use of outdated automated solutions, a lack of driving technology development, sparse automation investments, limited flexibility, insufficient use of automated solutions, inadequate knowledge among the automation suppliers and a limited number of automation suppliers with an understanding of the needs of the wood products industry. In the information system, the communication between the management level and the shop floor level was identified as problematic due to different views on the right type and amount of information needed. In the material handling system, the challenges involved the utilization of a bulky raw material, its relatively high transportation costs and material scrap due to unoptimized internal logistics. The management system faced issues of quality management, lack of leadership skills, insufficient utilization of resources at managerial level, a focus on solving daily problems and not being able to share company objectives at all levels. Last, in the category others the challenges involved raw material variations, relatively high raw material costs, relatively high levels of product customization, somewhat low value added to the products manufactured, material waste and product rework, relatively long manufacturing lead-times, limited familiarity with and use of different manufacturing philosophies, lagging behind competitors from low-cost countries causing a fear of not being able to keep the manufacturing system in Sweden.

Many of the manufacturing challenges that were identified have been addressed in previous literature dealing with various industries. However, some manufacturing challenges were specific to the wood products industry; these were identified in the categories "the technical system", "the material handling system" and "others". In the technical system, the insufficient knowledge and understanding of the specific needs in the wood products industry among the automation suppliers was identified. In the material handling system, the utilization of a bulky raw material, its relatively high transportation costs and the material scrap due to unoptimized internal logistics were identified. Last, in others, the raw material variations, relatively high raw material costs, the low value added to the products manufactured and material waste and product rework were identified.

RQ2: What are the drivers and challenges for automation of manufacturing in the wood products industry?

Based on the findings presented in this thesis, it can be concluded that the drivers for automation of manufacturing in the wood products industry are related to the labor force, among other things. These drivers involve reducing labor stress, improving ergonomics, increasing labor safety and achieving greater labor flexibility. Other identified drivers included were a desire for market expansion, increased quality consistency, increased capacity and increased competitiveness – all strategic in nature. Additional factors driving automation of manufacturing in the wood products industry were meeting customer demand, increased productivity, greater profitability, decreased manufacturing costs and increased material utilization. The driver related to increased material utilization might be specific to the wood products industry since product rework and waste is a common issue (Kozak & Maness, 2003).

The challenges for automation of manufacturing in the wood products industry involved overcoming relatively high investment costs, the twin problems of insufficient skills and knowledge of the labor force, insufficient technical awareness and expertise within the manufacturing company, lack of strategies and short-term goals, lack of manufacturing flexibility, raw material variations, the lack of understanding among automation suppliers of the wood product industry's needs and resistance to change (the latter is described as a result of tradition being strong in the industry). The challenges regarding the raw material variations and the lack of understanding among automation suppliers of the industry's needs might also be more specific to the wood products industry.

RQ3: What content need to be considered when automation decisions are being made in the context of manufacturing system development projects carried out in the wood products industry?

In general, it can be concluded that when automation decisions are being made it is critical to ensure an alignment between these decisions and a firm's manufacturing strategy. Based on the empirical research that has been presented, several manufacturing strategy decision areas were neglected when automation decisions were made in the study context. The focus was rather placed on the manufacturing strategy decision area process technology, something which is in accordance with previous literature (Winroth, et al., 2007).

There is a clear need for a wider consideration of aspects when automation decisions are being made. The answer to the third research question concludes that the cumulative content that needs to be considered when automation decisions are being made can be derived internally by the company itself or be due to external aspects. Among the internally derived aspects of importance were organizational structure, organizational culture, organization improvement programs, inter-functional coordination, layout, process compatibility, process support, levels of automation, maintenance, type of automation, impact existing manufacturing system, skills and knowledge, physical and cognitive workloads, production planning, scheduling and control systems, quality control policies and practices, raw material variations, raw material waste, location, manufacturing capacity, product specifications, manufacturing costs and investment costs.

Externally generated aspects of notable importance were collaborative planning, relations in supply chains, communication in supply chains, responsiveness in the supply chain, the previous experience and knowledge of the automation suppliers, the number of sub-automation suppliers involved, time to delivery of automation equipment, customers' perceived value, competitors' actions and work environment regulations.

RQ4: How can the process leading to automation decisions in the context of manufacturing system development projects carried out in the wood products industry be supported?

Based on the findings, it can be concluded that the process leading to automation decisions in manufacturing development projects conducted in the wood products industry is not without difficulties. Among the challenges identified are lack of recognition for the strategic relevance related to automation of manufacturing, insufficient competence regarding automation of manufacturing and a decided lack of structured approaches supporting automation decisions. The findings show that the combination of these challenges can result in heavy reliance on automation suppliers and a loss of competitive advantages related to automation of manufacturing.

To support the process leading to automation decisions, companies operating in this industrial sector need to invest in human resources. This can be done in a variety of ways, for instance developing knowledge about automation of manufacturing among internal resources. It can also be done by prioritizing efforts to appeal to people with the right competencies to actually join the industry and consider it as a viable long-term career. Companies operating in the wood products industry will also need to consider the strategic benefits of automation of manufacturing. Furthermore, there is a need to consider the relevance of established routines and processes that can support automation decisions.

6.2 Theoretical contributions

Investing in automation of manufacturing can have significantly beneficial effects on a company's competitive advantages, although this is far from always being the case (Olson, et al., 2014). Decisions made during manufacturing system design are argued to be significant if the best results are to be achieved (Choudhari, et al., 2010; Bellgran & Säfsten, 2010). It has been further argued that these decisions need to be linked to a company's manufacturing strategy (Garrido-Vega, et al., 2015; Eisenhardt & Zbaracki, 1992).

One notable contribution of this thesis has been to increase knowledge on automation decisions in manufacturing system design from a manufacturing strategy perspective. Automation decisions are often dealt with in the manufacturing strategy decision area of process technology (Miltenburg, 2005). Nevertheless, some of the literature highlights the importance of refraining from creating a single focus on this particular decision area when making automation decisions (Winroth, et al., 2007). The argument goes that changes in one decision area can entail the need for changes in other decision areas in order to gain long-term manufacturing objectives (Gouvea da Costa & Pinheiro de Lima, 2008). This thesis contributes to the debate with its definitive identification of various aspects in different manufacturing strategy decision areas that need to be considered when automation decisions are being made (see Table 4.6).

In addition, by studying automation decisions during manufacturing system design, this thesis adds to the manufacturing system development field by identifying potential challenges related to such decisions and highlighting improvement opportunities (see Table 5.2 for more on this).

A final contribution of this thesis has been to extend the current understanding of manufacturing systems in the wood products industry. The research presented in this thesis provides novel insights about the drivers (Table 4.4) and challenges (Table 4.5) for automation of manufacturing in this industrial sector. It revealed findings consistent with prior literature *and* reported results that are additional to those previously published.

6.3 Industrial contributions

This thesis contributes to a better understanding of automation decisions in the context of manufacturing system development projects conducted in the wood products industry. The research which has been presented contributes to improved industrial practice by providing a set of guiding suggestions that aim to support companies operating in this field to make informed automation decisions in manufacturing system development projects that they undertake. Greater knowledge on the content of automation decisions, which is concerned with the different aspects that need to be considered when automation decisions are made, has been produced.

In addition, the guiding suggestions contribute with new knowledge regarding the process leading to automation decisions by providing insights on weak points and potential improvement opportunities. These insights are based on empirical studies on automation decisions made in manufacturing system development projects conducted in the wood products industry and in the automotive industry. The reason for studying the latter was to gain insights from an industry that is assumed to have extensive experience in the area. Landscheidt and Kans (2016) state that these types of studies should be encouraged since they create opportunities for the wood products industry to observe how other industries have implemented automation of manufacturing, and through that adapt suitable concepts.

6.4 Limitations and future research

There are a number of limitations inherent in the work, and various options for pursuing further research in the field. A first limitation is that the empirical research underlying this thesis is based solely on Swedish companies. Research that examines similar companies from other countries (and with larger sample sizes) could be valuable. Furthermore, research that takes in other industries would make for an interesting exchange of experiences, commonalities and differences.

Second, the underlying research methods were chosen with the aim of gaining knowledge on certain phenomenon through exploring cases in depth and in relation to prior research, and not to obtain statistical generalizability. This carefully defined aim needs to be taken into consideration if the research is to be understood in full. For example, although Paper V and Paper VI are based on a single case study, it must be noted that the chosen research method enabled a unique opportunity to follow each case closely over time; this provided valuable in-depth data and a good level of understanding.

Third, it would be interesting to study automation decisions in manufacturing system development projects where both the case companies' and automation suppliers' perspectives are examined. Exploring the automation suppliers' perspectives would add additional understanding for how automation decisions are made and what they are based on. Thus, a related question for future research is to consider in what sense the automation suppliers influence automation decisions in the context of manufacturing system development projects conducted in the wood products industry. An additional question would be to look at how the automation suppliers can support their customers in utilizing the full benefits linked to investments in automation of manufacturing.

Fourth, the manufacturing strategy point of view was placed center stage in relation to automation decisions. Findings show that while some previous literature reviewed automation decisions in relation to some manufacturing strategy decision areas, such as human resources, other important decision areas (for example capacity) did not receive as much attention. This has been addressed to some extent here, but there is probably still a need for further research.

Fifth, because this thesis focuses on automation decisions from a manufacturing strategy perspective financial justification related to the manufacturing system development projects were excluded. Since financial justification plays an essential role in such projects, future research could combine these two perspectives to support decision-makers when conflicts occur.

Last, this work presents a set of guiding suggestions which aim to support decision-makers in the wood products industry to make informed automation decisions when designing manufacturing systems: it would therefore be valuable to use and evaluate these guidelines in the context of manufacturing system development projects conducted in the wood products industry.

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