Final Research Paper

Advanced Manufacturing Techniques and Technologies in the Oregon Forest Cluster

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1. Introduction

Similar to other manufacturing industries, the wood processing industry has been undergoing rapid changes in recent years. Since the nineteenth century and the invention of the steam engine, the use of electric power and automation enabled by electronics and IT have increased industrial productivity enormously. After having completed the three industrial revolutions shown in *Figure 1*, we are now facing the next stage of technological advancement known as the fourth industrial revolution.

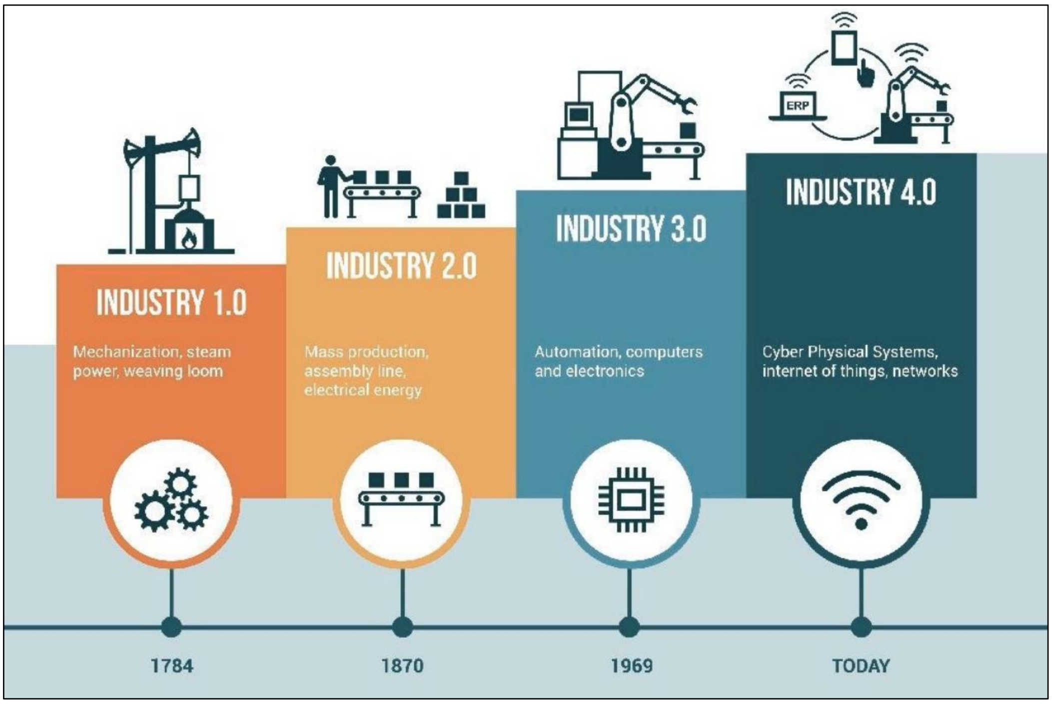


Figure 1: The four industrial revolutions [1]

Even though it is an omnipresent topic in the media at the moment, there are still many obscurities due to the lack of a set definition of the term itself.

Causing confusion, different terms for this development have established in Europe and in the USA. While it is promoted as "Industry 4.0" (also referred to as "I4.0") in Europe, the phrase "Smart Manufacturing" (also "Manufacturing Renaissance") is more common in North America. [2]

The following subchapters will explain, what Industry 4.0 or Smart Manufacturing is and why it is important, which will lead to the purpose of this research project.

1.1. Industry 4.0 or Smart Manufacturing

Industry 4.0 is currently a "hyped" topic and is highly covered by the media, fills whole exhibitions and is the reason for many events. Nevertheless, there is a discrepancy between the promoted image of the technological revolution and the real impact on today's industrial companies.

The rather vague and elastic phrase "Industry 4.0" can shortly be summarized as "technological evolution from embedded systems to cyber-physical systems" [3] (CPSs). CPSs are sensors, machines, workpieces or IT systems, which are connected along the value chain and are able to interact with each other by the use of internet-based protocols. By gathering and analyzing data across machines and enabling faster, more flexible and more efficient processes, production with decentralized, intelligent systems makes it possible to produce higher-quality goods at reduced costs, which in turn increases overall manufacturing productivity. The Boston Consulting Group has identified the most foundational technology advances, by which this transformation is powered, the nine technological pillars shown in *Figure 2*. [4]

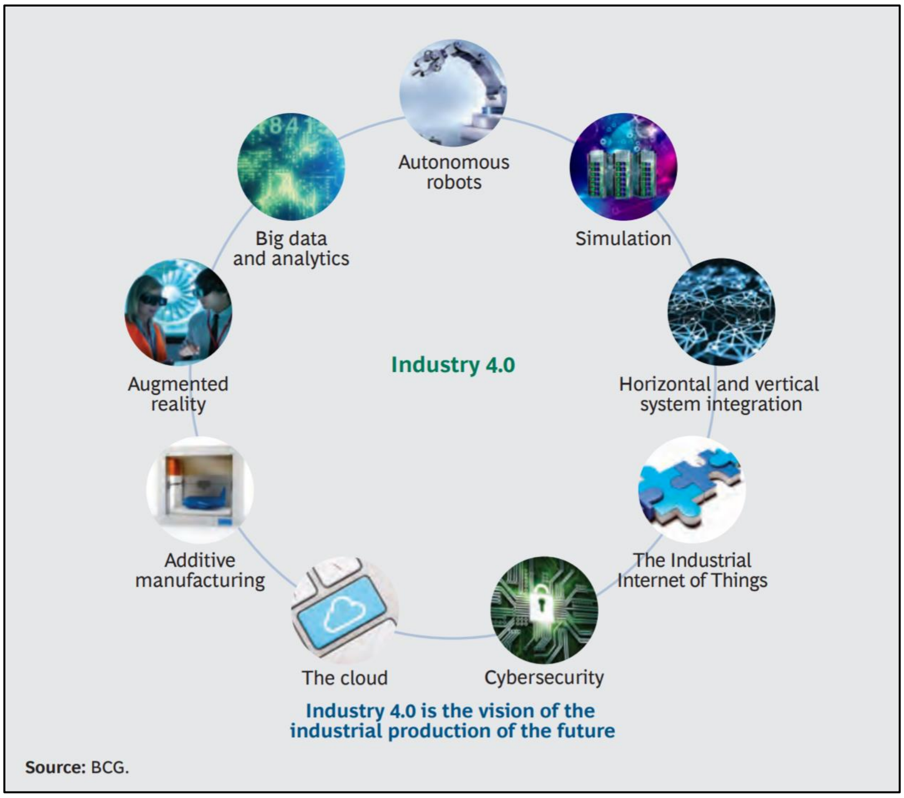


Figure 2: The nine pillars of technological advancement [3]

Autonomous robots, simulation, horizontal and vertical system integration, the Industrial Internet of Things (IIoT), Cybersecurity, the cloud, additive manufacturing, augmented reality and big data and analytics provide the basis of Smart Manufacturing. Many of them are already used in modern businesses, but in the course of Industry 4.0 these individual elements from the physical and virtual world will interconnect to form a fully integrated and automated production system.

The "revolution" started in Germany. The Federal Government realized that the rapid social and technological development demanded new and extensive innovations. Therefore, Industrie 4.0 was adopted as one of the main future projects in the "Action Plan High-tech strategy 2020". This strategy promotes the computerization of the manufacturing industry with the goal of an intelligent factory. A smart factory is characterized by adaptability, resource efficiency and ergonomics and leads to a greater overall efficiency. This results in a change of traditional production relationships among suppliers, producers, and customers — as well as between human and machine. In April 2013, the working group Industrie 4.0 published its final report "Recommendations for implementing the strategic initiative Industrie 4.0". It sheds a light on the requirements to secure the future of the German manufacturing industry and to expand the country's leading international position by improving its competitiveness as a production location. [5] und [6]

As the fourth industrial revolution spread around the world, other nations established different terms for I4.0, whereas their definitions closely resemble each other. In the US, several agencies like the Department of Energy and the National Institute of Standards and Technology coined the term Smart Manufacturing [2]. Kusiak from the University of Iowa, USA, defines Smart Manufacturing as "an emerging form of production integrating manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, control, simulation, data intensive modelling and predictive engineering. It utilises the concepts of cyber-physical systems spearheaded by the internet of things, cloud computing, service-oriented computing, artificial intelligence and data science" [7].

Japan started an even more ambitious initiative called "Society 5.0". On its official website the government declares that they "aim at creating a society where we can resolve various social challenges by incorporating the innovations of the fourth industrial revolution [...] into every industry and social life. By doing so the society of the future will be one in which new values and services are created continuously, making people's lives more conformable and sustainable. This is Society 5.0, a super-smart society" [8].

These are only a few examples for this latest technological development. While there are many more (though similar) initiatives and more comprehensive definitions available, they all share one main goal: to remain competitive. Their common agenda includes the use of information and communication technology (ICT) and advanced data analytics to improve manufacturing operations within the companies as well as up and down the supply chain. [2]

The initial need to implement new digital technologies results from various upcoming challenges. Not only do more globalized markets demand constantly increasing competitiveness, but manufacturers are also faced with customers that increasingly wish for individualized and at the same time cheap products. This entails a growing number of variants and increasing complexity in the whole production process, mostly resulting in a batch size one production. Thereby a strong need for the use of automation and interconnected systems arises, because the overall aim is to produce as economic as possible including resource efficiency and short processing times. Additionally, the demographic change causes an aging population and for this reason a shortage of skilled labor. This increases the need for automated and intelligent processes.

The concomitant challenge, that can be managed with the help of new digital technologies as well, is production improvement. To continuously improve production, a detailed overview of all manufacturing elements is vital. In a Smart Factory each part of the production system is monitored, and its key values are recorded. This data collection provides many ways of improvement. For instance, bottlenecks can be identified easily, production flows can be reorganized if necessary, the reliability of single machines and the whole plant can be calculated via downtimes, or short- and long-term production planning can be facilitated.

1.2. The Research Project

Naturally, this recent development has also been affecting the wood processing industry. In an age of globalization and international markets, the steadily increasing price pressure makes it harder to stay competitive. Thus, it becomes vital - especially for smaller companies - to work as effectively, efficiently and economically as possible. Even though complete adoption to Industry 4.0 might take many years, the next five to ten years will be crucial for companies to either take advantage of this trend or lose competitiveness. As a direct consequence, Oregon's wood products manufacturing industry is rapidly implementing new techniques and technologies to improve the competitiveness of their operations. For instance, robotics is becoming much more common within wood products manufacturing and advanced monitoring via the Internet of Things is growing.

This research project focused on gathering information on the current situation of the wood products industry in Oregon to obtain a comprehensive overview of the implementation of "Industry 4.0" elements and inhibiting factors within this process. As there was no consolidated data like this up to this point, this was a very important first step to support the individual development of regional companies. For this purpose, investigating the state-of-the-art was significant but insufficient. Most published media on this subject is rather abstract and concentrates on presenting the latest innovations. This might be a good opportunity for orientation and inspiration, but there is no reaction to regional conditions and problems.

The study was conducted in the context of the Oregon Forest Cluster. According to the Oregon Board of Forestry the “Forest cluster” consists of the firms and organizations which operate in the production of primary and secondary wood products and a wide range of forestry services. The cluster intends to examine the “geographically concentrated and interconnected economic activities and linkages to customers and suppliers” [9]. As organizations operating in forest resource management as well as educational and research institutions are regarded as members of the forest cluster too, it was considered as the suitable environment for the study. Especially because the concept of the cluster has its focus on the individual (competitive) advantages of a region and how their activities are networked economically. As a result of outside influences like changing wood supply and globalization, most of the industry is now localized around major transportation corridors. Particularly the rural companies and communities of eastern and central Oregon are affected by this contraction of industry and employment. [9] and [10]

Although there are already some individually successful companies, there is an urgent need to assess the current technological situation of the wood industry in Oregon and to provide different approaches for a sustainable improvement. In order to support the regional companies with regard to the current situation explained above, the overall objectives of this research project were to:

- identify the state-of-the-art in Oregon's wood products manufacturing industry with respect to implementation of advanced manufacturing techniques and technologies,
- identify the “average” use of new digital technologies and compare it to the state-of-the-art to reveal any need and potential for improvement,
- identify hurdles for the adoption of advanced manufacturing techniques and technologies and thereby facilitate the development of a roadmap for a future technology strategy

The results, which are presented in this research report, will be relevant for the future development of the wood processing industry in Oregon. By describing the average use of advanced manufacturing techniques and technologies at the moment, the requirement of an overall picture of the actual situation will be met. Furthermore, the identification of key hurdles in the adoption of new technologies is necessary to overcome these difficulties and to take the next step towards Industry 4.0.

The Oregon Forest Cluster will benefit from this work. To induce a sustainable change in the individual businesses they must recognize the necessity for transformation. Awareness will be raised by revealing the current situation with the existing key hurdles and, at the same time, providing a technological forecast triggering a process of self-reflection.

2. Research Methods and Workflow

To facilitate a structured approach, data for this study was collected in three phases. The first phase consisted of secondary research using industry-focused trade journals. Phase two concentrated on interviews with key experts in the Oregon wood products manufacturing industry as well as equipment vendors to the industry. The final and longest phase contained an online survey among Oregon wood products manufacturers and produced the results for the final step of evaluating, drawing conclusions and identifying improvement measurements.

Phase I

The purpose of Phase I was to orient the researchers to current techniques and technologies documented in existing literature. Therefore, various journals, papers and other publications were screened for their importance for the research topic, whereby the ones which appeared relevant were analyzed more detailed. Not only literature from within the United States was examined, but also international publications with the objective to get a general overview of the industry. Specifically, publications included in this evaluation are:

- Timber and forestry e-news *(Australia)*
- Logging and Sawmilling Journal *(North Vancouver, B. C., Canada)*
- Timber West *(Edmonds, WA, USA)*
- International Forest Industries *(Berkhamsted, United Kingdom)*
- FDMC – Woodworking Network *(Cedar Rapids, IA, USA)*
- Wood Business - CFI (Canadian Forest Industries) *(Simcoe, ON, Canada)*
- OptiSaw forum publications *(Canada)*
- Panel World *(Montgomery, AL, USA)*
- Timber Processing *(Montgomery, AL, USA)*
- Millwide insider – the magazine from USNR *(Woodland, WA, USA)*
- HOB – Die Holzbearbeitung *(Ludwigsburg, Germany)*
- AWISA (Australian Woodworking Industry Suppliers Association Limited) *(Bowral, NSW, Australia)*

The journals listed above were selected because they contain up-to-date information on technological advances in the forest products industry and its suppliers. The issues were examined methodically for relevant information, beginning with the latest issue and going back in reverse chronological order. Depending on the topicality of the information, publications from at most the last two years were integrated. This rather short time frame was considered as adequate because of the rapid technological changes. Articles were deemed relevant if they introduced new processing techniques or technologies for the wood industry.

Additionally, independent papers concerning the topic found on the internet were used to extend the compilation of the latest I4.0 developments.

The findings of this phase were summarized to provide an overview of the current state-of-the-art also for companies in the wood processing industry.

Phase II

The second phase was built on the information gathered in Phase I, using expert opinions from managers in Oregon's forest cluster. For this, the researchers made in-person visits to multiple machinery and equipment manufacturers in the region. The identification of site visits was partially informed by the previous phase and supplemented by knowledge of the research team.

The selected companies are known to be highly digitalized and to offer state-of-the-art technologies. This is why interviewing their technology specialists was very valuable for this research study as their input presented a comprehensive picture of current and future technological possibilities. Questions asked at these visits addressed the techniques and technologies actively applied in the companies' production as well as the companies' plans for development towards Industry 4.0. Furthermore, general questions about the technological advance in wood processing gave insight into the personal experience of the managers and their perception of the forest products industry. Also, the companies' production was toured to get a personal impression of their use of technology and working methods.

As a result, the statements of the various experts were used to expand the report of the first phase.

Phase III

After gaining a better understanding of the state-of-the-art with respect to manufacturing techniques and technologies currently used by Oregon's wood products industry, an online questionnaire was developed to allow an assessment of the overall adoption of key techniques and technologies.

The decision to conduct the survey in a web environment was made because it is a very fast and cheap way to gather information. To achieve a high response rate and also to benefit the respondents, the *Tailored Design Method*, according to Dillman [10], was generally followed for design of data collection. "Tailored design is a strategy that can be applied in the development of all aspects of a survey to reduce total survey error to acceptable levels and motivate all types of sample members to respond within resource and time constraints" [11, p. 16].

Especially the implementation and design of an online survey entailed special challenges. The book provided detailed guidelines on this topic. By following these step-by-step, it was possible to optimize the survey invitation as well as the layout and handling of the questionnaire for desktop and mobile application. To construct the questions, various aspects had to be considered for keeping the total survey error as small as possible. Therefore, the surveyor needed to minimize four main types of errors to improve the results: coverage, sampling, nonresponse and measurement error.

A certain *coverage error* always occurs because data is collected only from a sample of the target population, but the results are generalized to the whole [11, p. 4]. There is always a risk, that the statistics of the sample are not representative for the whole population. For this reason, it is important to reach as many members as possible, in this case companies in Oregon's wood processing industry. This was achieved by sending out the initial invitation email to all members of the Oregon Forest Industry Directory (OFID). Nevertheless, a complete coverage regarding diversity of businesses could not be guaranteed as it depends on the individuals whether or not to participate. For minimal error, participation would be required from all different sectors within the forest products industry in Oregon as well as all different sizes from one-person businesses to manufacturing groups

"*Sampling error* is an unavoidable result of obtaining data from only some rather than all members on the sample frame" [11, p. 5]. It is the deviation of the survey statistic from the true value of the whole population. This error was also reduced as much as possible by using the OFID for distribution. It covered most of the companies without having to do additional research through federal offices.

Even though the *nonresponse error* is not defined by the number of people that didn't respond, it can be significantly reduced by a high response rate. This is because this error "occurs when the characteristics of respondents differ from those who chose not to respond in a way that is relevant to the study results" [11, p. 5]. Thus, the key is to reduce people's reluctance to participate in the study, as this increases the response rate and includes a bigger part of the target population and results in a decreasing error due to nonresponse.

Another severe source of error is the design of the questions themselves. It has a great effect on the participant's perception of the question and the addressed topic. To minimize the *measurement error* and to get adequate answers for the study, it is important to make sure that the target population fully understands the questions asked so they provide evaluable answers. This was achieved by different measures. One was to avoid open-ended questions as often as possible and asking closed ended questions instead, using a nominal or ordinal style depending on the question and the required responses. Furthermore, even though the participants were supposed to be familiar with the technologies addressed, an easily understandable word choice was preferred, and an excessive use of technical terms was avoided to facilitate and encourage the completion of the questionnaire.

Even though the OFID was used for contacting possible participants, several members are not part of the target population. This is why the first question was designed to sort the eligible participants from the non-eligible ones by asking if their company is an Oregon-based manufacturer or distributer of wood products.

An overall difficulty was to avoid using the terms Industry 4.0 or Smart Manufacturing in the questionnaire, as any input could have expanded the knowledge on the topic. This would eventually have altered the results of the survey and defeated the purpose to assess the level of knowledge in the wood processing industry. Therefore, these terms were simply rephrased as new manufacturing techniques and technologies.

Different measures were taken to reduce people's reluctance to participate in the survey in the first place or to prevent them from dropping out before completion. Anonymity of the participants was important to encourage them to give truthful answers even though this also includes revealing weaknesses. In addition to that, the duration to finish the questionnaire should not be too long, which is why the length was reduced to a total of 26 questions, taking approximately ten minutes. To reduce respondent dropout, each question showed up on a separate page to avoid overwhelming the participants. Additionally, a progress bar should motivate them to keep going and the option to go back to previous questions was added to enable overthinking already given answers.

After a first draft of the questionnaire had been completed, it was tested on employees of Oregon State University. Their input was used to improve phrasing of questions and answer options for a general better understanding. Through this testing, minor changes were introduced. Also, the preferred answer types (e.g. sliders or matrix tables) were determined and advice on additionally requested answer options (e.g. “do not know” or “none of the options”) was taken. The final version of the questionnaire can be found in Appendix A..

Before the distribution of the survey, approval was sought and received from OSU’s Institutional Review Board (IRB) regarding research with human subjects.

An invitation was emailed to all the 1853 addresses registered in the OFID. After one week a reminder email from one of the advisors followed to achieve a higher response rate, giving the invitees another week to participate.

Finally, the responses were analyzed, and a detailed evaluation revealed the average situation and usage of advanced manufacturing techniques and technologies in this region and their main difficulties with the adoption to Industry 4.0.

3. Results

The collected data was analyzed to support the construction of a roadmap for the forest cluster including the required changes in current strategies. Although smaller companies would, theoretically, be able to adopt new technologies faster due to their simpler and more flexible structures, in reality they are often sluggish. The reason for this is that even though the topic "Industry 4.0" is omnipresent, many managers do not fully comprehend the impact it will have on their operations and, therefore, are at risk of being left behind. In order to avoid this, the companies must recognize the necessity to change, which is why this research project will contribute to the enlightenment and motivation of the Oregon Forest Cluster to stay competitive in regional, national and international markets. It can be expected, that the hurdles for adoption of advanced manufacturing technologies are not only technical but also of human origin. This is a very important factor to bear in mind because it implies that for a successful transition, both technology and personnel management is required.

A detailed collection of the results and evaluation of the research phases is presented in the following chapters.

3.1. The State-of-the-Art in the Wood Processing Industry

This chapter is divided into three parts to illustrate the state-of-the-art from different points of view.

3.1.1 Literature Review

The following short literature review points out the most important elements of smart manufacturing according to the journals and other publications listed in the previous chapter Research Methods and Workflow. Thereby, this review describes the general state-of-the art in the wood and forest industry.

As was expected, the topic of robotics was highly covered by different journals and papers. The journal *timber & forestry e-news* brought up various case studies for successful implementation of robotic systems. The German timber engineering equipment manufacturer Hundegger, for example, utilizes a robotic unit to process highly complex six-axis connections, which they were not able to manufacture with their earlier machines. One of the company's managing directors Charlie Hutchings said in the interview that utilizing robotics within their more traditional machines is at the forefront of their cutting technology. He is convinced that the use of robotics in a broader sense will certainly increase both for materials-handling and even assembly applications, because customers want their business processes to be efficient. [12]

In a later issue they interviewed Hartmut Schrage (Homag) at AWISA 2018. The fair showed that "robotic systems, together with artificial intelligence software, are now firmly established as an integral part of the cabinet-making industry" [12]. Schrage is optimistic about the opportunities robotics will offer the industry. At the moment mainly statuary robots are used to perform repetitive tasks but they soon will move independently und carry out more complex tasks. [13]

Paint spraying robots are already implemented by many companies, mostly of the secondary wood products sector. *FDMC* introduced the awarded robot system "Ready2spray" created by Dürr. It can be used for the wood, plastics, and metal industry and "consists of a six-axis robot equipped with high-end technology for the application of solvent- and water-based, one- and two-component paints" [14]. The manufacturer says "the robot system is fully Industry 4.0-ready" [14].

Closely related are the automated guided vehicles (AGVs) utilized by Muskoka Cabinet Company. In their production these AGVs move material around the shop. The vehicles are designed to maneuver around the shop floor by themselves and slide under the cart, that contains the required parts, to pick it up and move it to the next station. Security is granted by flashing lights on the AGVs to alert people. The products are continuously tracked by an intelligent RFID system, which enables real-time control. One of the biggest advantages of this system is that the employees have more time to do skilled tasks in the manufacturing process and thereby saves a lot of money. [15]

Literature also emphasizes the usefulness of sensors, sensor networks and embedded systems. A representative example for this is the acoustic circular saw monitoring mentioned in the *Canadian Forest Industries* journal. This new technology increases productivity and decreases wear of sawblades at the same time. The CSM Heartbeat system monitors the sounds emitted by the saw blade, its "heartbeat", like a stethoscope. If there is any noise in the recording, impulses are immediately sent on to the control unit, that reduces the feed rate for a second to avoid damage and downtime. After this short reduction, the sawing plant immediately picks up its normal speed again. Furthermore, the system adjusts the speed depending on the general condition of the saw blades. [16]

At the OptiSaw conference 2017 in Vancouver the case study of Maibec was presented. The company implemented PMP Solutions' Manufacturing Executive System in their production to improve the overall mill performance. The results included faster problem diagnostics, easy scheduling, better drying results and higher throughput. Maibec's overall impression of the new system is positive as real-time information leads to more action, enables improvements and empowers employees. [17]

Remote monitoring, maintenance and servicing is a great opportunity both for machinery manufacturers as well as for their customers in the wood processing industry. A rather simple version of remote servicing is offered by Vekta Automation. All their "saws include a battery-powered camera system which allows an operator to show a remotely-connected engineer what the problem is in real time – from offering electrical or mechanical drawings, remote log-in or even sending someone to site" [18]. Vecoplan's Live Service system goes even one step further: this technology equips the company's customers with special Augmented Reality glasses based on Google Glasses. With this new digital technology customers can directly connect to technicians if they need help troubleshooting and servicing their machines. [14]

Digital technologies enable the production of new panels based on digital staining on plywood. The highly-automated production of North American Plywood integrated an Inca Onset high-definition inkjet press into its production process, which "employ[s] a carefully calibrated digital staining and finishing process" [19]. This DesignPly system is able to replicate various wood grains and other patterns and thereby creates the effect of top-grain veneer species on particleboard, MDF, metal and melamine panel. [19]

As artificial intelligence and machine learning are getting more attention and slowly asserting themselves in production processes, Biesse launched its own AI platform, Sophia. "Sophia is a digital platform that provides users with access to more machine information and initiates concrete actions to optimise performance and monitors the quality of the work produced, anticipating the causes of faults and providing clear solutions to resolve any anomalies. The data gathered and analysed by artificial intelligence is transformed into useful data to help optimise customer production and product quality, providing extremely valuable opportunities for growth. This information also provides customers with tools to prevent problems that could damage production. Thanks to SOPHIA, Biesse can take proactive steps to contact customers, reducing machine stoppages and inefficient time-wasting.” [20]

3.1.2 Expert Opinions / Company Visits

The following section displays the view of equipment and machinery manufacturers on the state of the art in the wood processing industry.

Because the experts gave tours of their companies and explained their manufacturing processes first, the researchers were able to understand their way of working and their mindset. Furthermore, this made it easier to comprehend the answers given in the second part of the visits, where the researchers had the chance to ask questions.

The overall impression gained from these conversations is that the experts are well informed about the advanced manufacturing techniques and technologies described above. Nevertheless, this does not automatically imply that they are transforming their companies into a Smart Factories or plan on doing so. The deciding factor in industry is always payoff time, so new technologies always need to possess an outstanding feature which significantly increases production speed and output.

The first block of questions addressed the topic data and data processing. It revealed that even though cloud storage is frequently used by private persons, companies have a more defensive attitude towards this internet-based data storage system. Instead, they use inhouse servers. Their main arguments against the cloud are transmission speed and data storage period. One part of the experts is worried that the use of cloud storage would be too slow and too expensive for huge amount of storage space. The other part holds the contrary opinion, in which online storage is not required because data should not be stored longer than necessary.

Machinery manufacturers also have to consider the attitude and standards of their customers. Especially in the wood processing industry, many companies still rely on paper work and some do not even have a sufficient internet connection, which is the main requirement for cloud storage. Therefore, equipment manufacturers often store customer data locally at the individual production sites and transfer it regularly to their servers. This reflects the general use of wireless data transmission. Both online storage and transmission are eyed suspiciously due to potential data security breaches.

However, in terms of data processing and analysis it does not matter how the information is stored. Even though a majority of companies gathers a lot of data, they do make use of it. The only reason for this is lack of knowledge. Businesses often do not have an insight into the possibilities of data processing and analysis, they are not able to distinguish between relevant and redundant information. As a consequence, those companies are also not able to recognize the great potential to improve the production process.

The last question of this block inquired whether the visited companies process data in real time. All experts responded in the same way, they stated that processing speed is essential as customers are not open to slowing their systems to match up with slow data analysis. With steadily increasing production rates, real time data processing becomes one of the main requirements of a plant.

Next, the techniques and technologies actively applied in the companies' production were addressed as well as their customer service and the companies' plans for development towards Industry 4.0.

Offering remote servicing or maintenance for customers is taken for granted nowadays. Companies are happy to be able to provide this service because it is less time consuming and expensive than to send out specialists to widely scattered and remote sites. But since managers are often concerned about data privacy and prefer specialists on site in case of technical errors, they must be convinced of the advantages first. This is an essential step because the customer's permission is always needed to access their systems. Of course, if there is a severe malfunction, which cannot be fixed remotely, a specialist will provide on-site support.

Surprisingly, none of the experts had heard of the term "pay per use". The business model behind it (to pay only for the time you use the product / service), however, is well-known. But at least in the forest products industry it does not attract wide interest. One of the companies, for instance, considered leasing veneer patching machines and software and already had a concept for this, but their customers were not interested, they prefer buying their own machinery, mainly for tax related reasons. Generally, mostly maintenance free equipment, like meters, is offered with the pay per use model. Nevertheless, some experts have been thinking about this model a lot. Even though leasing is risky because high tech equipment is very sensitive and easily damaged, in their opinion there will be a higher demand in the future. The reason for this is the situation of the market, which is slowly becoming saturated, and therefor especially smaller mills will not be able to afford buying new systems.

Machinery and equipment manufacturers are in contact with wood processing companies every day and should have a good impression about their situation and inhibiting factors for a digital transition. Two inhibitors were mentioned as the most severe, costs and lack of skilled employees. New technology must have a short payback time or else it is not worth investing in. But there is also the cost of downtime when switching to a new system. Every company wants to avoid shutting down production. This is why suppliers tend to offer an installation over weekends. The second big inhibitor is a lack of skilled employees. If there is not enough know-how and there are no specialists for the affected field, the company is likely to drop their plans out of insecurity regarding effective implementation and maintenance of new systems. There is always a risk with new technologies but fearing them may result primarily from a lack of training and knowledge. Thus, it is vital to build up commitment to the new manufacturing techniques and technologies through training. The most important factor for a successful transition is that employees understand the software, equipment and machines they are working with. Only in this way will the customers will be able to independently maintain the new systems.

According to the interviewed experts, the level of awareness regarding smart manufacturing in the wood industry is rather low. The companies are only interested in new technologies that increase profit. Still, the general attitude towards change mostly depends on the background of the responsible area manager. Regardless of the attitude and future plans, businesses in the same industry sector know at least how their competitors' production works and this is often enough. Therefore, what appears to be obvious and easy solutions for improvement from the outside are rarely implemented due to a lack of knowledge. For this, educational measures would be important to support the wood processing industry, to simply reveal new digital possibilities and how they can maximize their profit through purposeful implementation.

The final question aimed at a forecast of the most promising new technologies for the wood industry. The experts shared their opinions about Augmented Reality for remote maintenance. They think it will take some time until it becomes more reliable but then it will be of great use for all industry sectors. Furthermore, they are convinced that production management and surveillance systems (like an MES) will play an important role in the future, especially predictive maintenance, intending to prevent unexpected equipment failures. Hope is also invested in a grading system, which is already available and automatically grades lumber. A human grader reviews the decisions of the system, which projects the quality class from above onto the moving pieces with the help of 3D recognition. The graders can still change the category if they disagree. Furthermore, the experts gave information about a technology they consider as not promising for the wood industry. They were talking about collaborative robots (Cobots) and their rather long pay-off time due to reduced operating speed compared to traditional robots. The issue of predictive maintenance is also persued, for example by measurement of vibrations in machines to supervise the wear of sawblades. Another emerging innovation they mentioned is an identification method for logs. Thereby the roundwood is scanned and an individual 3D-model of each log, a “fingerprint”, is created.

Contrary to the ongoing hype about I4.0, one of the experts made a rather disillusioning statement about all the new technologies and digital possibilities, and their effects on the manufacturing industry:

“Industry 4.0 made everything easier and faster but didn’t change much.”

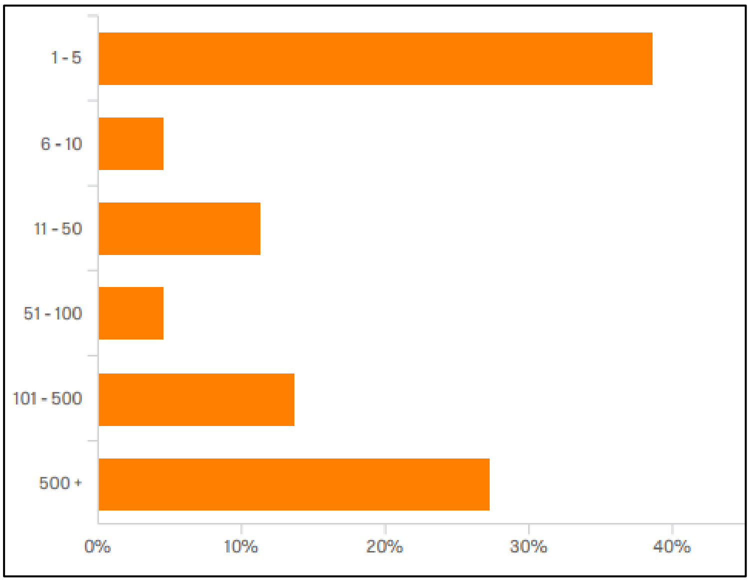
3.1.3 Evaluation of the Online Survey

In contrast to the previous section, this part summarizes the collected information on the state-of-the-art of the surveyed wood processing companies.

The target population were Oregon-based manufacturers and distributers of wood products, which were identified through the Oregon Forest Industry Directory and invited to the survey.

In total, 79 of the contacted companies participated in the survey. Fifty-eight percent (46 companies) were Oregon-based manufacturers or distributers of wood products and were qualified to continue with the questionnaire. The completion rate was 63%.

Most of the surveyed companies operate in the primary (49%) and secondary (39%) wood products sector, where primary wood processing businesses are for example sawmills, veneer or panel producers and secondary wood products include furniture or flooring. Only a few are in forestry services (5%) or are not covered by the given sectors (7%).



The distribution of company size measured by the number of employees is shown in *Figure 3*.

It shows that most of the participating companies in the Oregon Forest Cluster are either very small (1-5 employees) or large businesses with over 500 employees.

Only relatively few belong to the small and medium-sized companies in between.

Figure 3: Distribution of number of employees of the surveyed companies

Anticipating the result of the very last question of the survey, it becomes explicit that there is an urgent need for information on the whole topic “Industry 4.0”: The vast majority of the surveyed businesses has either no strategy towards I4.0/Smart Manufacturing (41%) or they are not even familiar with these terms in their company (52%). Only a small minority of 7% already has a strategy and these are only large businesses with over 500 employees.

By answering the next questions, the participants helped to create an image of the current initial situation regarding infrastructure, competitiveness and level of awareness within their company.

All of the infrastructure categories were predominantly rated as good or excellent by

- 71% for transportation and accessibility
- 85% for communication network, and internet availability and speed
- 76% for building condition and
- 85% for energy supply.

The responses to the inquiry of the competitive standing compared to other companies in the sector differed more from each other as the question differentiated between competitiveness on regional, national and international markets. As illustrated in *Figure 4* on the next page, the percentage of surveyed businesses, which describe their competitive standing as good or excellent in regional markets is very high (74%), but strongly decreases with increasing size of the market. In national markets only 54% feel good or excellent about their competitiveness and in international markets the poor and very poor competitive standings even exceed the good ones with 34% versus 21%.

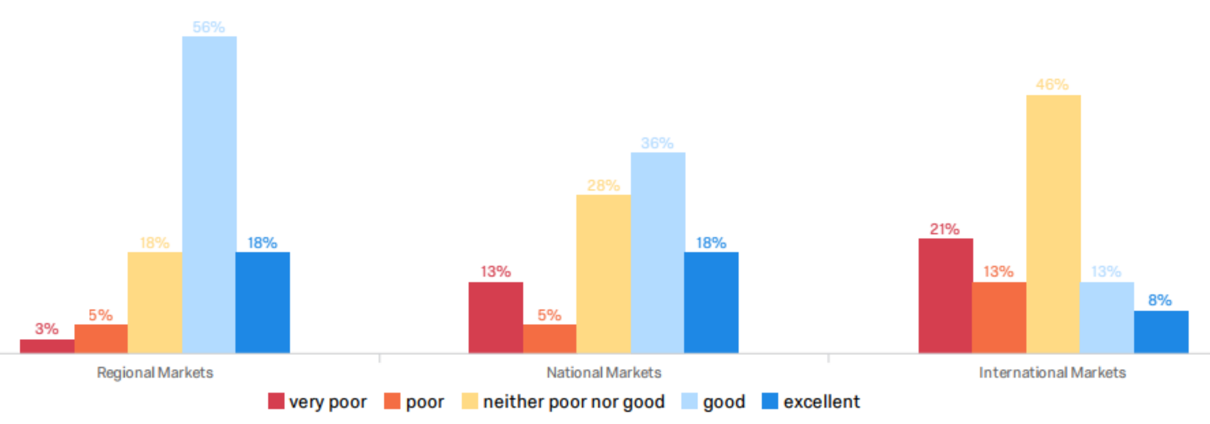


Figure 4: Self-rating of wood processing companies regarding their competitiveness

This is a significant indicator of the fact that, in view of the ongoing globalization of markets, the companies in the Oregon Forest Cluster will have to improve their situation very soon in order to be able to remain competitive. Implementing advanced manufacturing techniques and technologies can be an important step for this transformation.

An overall high awareness for different manufacturing technologies and techniques within the company is only existing in three out of nine categories: Digital Connectivity, Digital Customer Interaction and New Business Models. The average level of awareness in the six other categories is very low; these are: Virtualization, Robotics, Big Data, Predictive Analytics, Cloud Computing and Autonomous Systems. These results are proof that there is a high need for education and enlightenment concerning new technologies and techniques to raise awareness among the members of the wood processing industry.

Considering this, the evaluation of the subsequent question is interesting. Even though the participants rated their level of awareness as rather low, they are convinced, that the techniques and technologies listed in the previous question might support their companies to

- deal with globalization and future markets,
- deal with complexity,
- reduce consumption of resources,
- provide mass customization,
- implement new business models,
- increase flexibility and
- minimize errors along the supply chain.

As predicted by the experts, the major inhibitors for the surveyed wood processing companies to implement new manufacturing technologies are a lack of skilled workforce and unclear (financial) benefits from investments in technology (see *Figure 5*, page 17).

Only minor inhibitors are:

- lack of general knowledge about new manufacturing technologies and techniques
- lack of knowledge of service providers and equipment manufacturers
- no roadmap for implementing
- current facilities out-of-date
- pending questions about data security, privacy and ownership

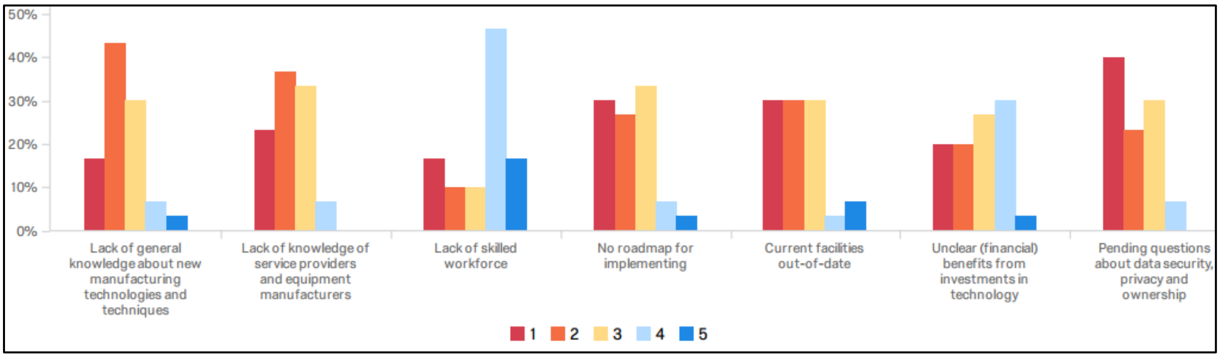


Figure 5: Rating of possible inhibitors for implementation of new technologies

The lack of skilled workforce was confirmed by the next question which inquired the level of expertise in the fields

- IT-infrastructure,
- data analysis,
- data and IT safety,
- automation,
- robotics,
- user interfaces/assistance systems,
- additive manufacturing,
- cloud services and Big Data
- application of simulation programs.

Solely the average level of expertise in the category IT-infrastructure was rated as high. All other fields exhibit a lack of expertise within the interviewed companies.

In order to improve this situation, employee training is an important measure to expand the knowledge of the workforce of a company and therefore of the whole Forest Cluster. However, as shown in *Figure 6* the majority of respondents does not offer any trainings in their business or intends to do so in the future.

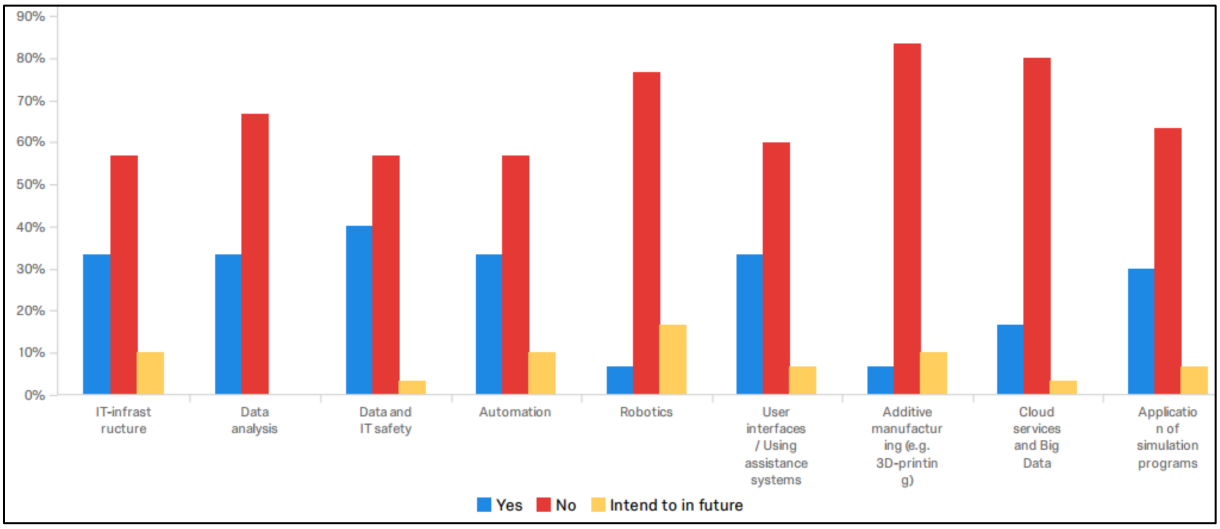


Figure 6: Rates of provided employee trainings divided by fields

To improve a production process, the collection, processing and analysis of machine data is essential.

The survey reveals, that only 45% of the companies collect machine data in any form. Of those, all but 7% process and analyze the collected machine data to show the performance of production (e.g. in form of Key Performance Indicators). In most cases, the companies use this for management purposes, for real-time production or a combination of both.

With 76%, a higher percentage of the surveyed companies uses analysis of process data. They apply at least one of the following operations (arranged according to choice count in descending order):

- performance analysis
- predictive maintenance
- data analysis for decision making
- predictive quality management
- smart facility and energy management
- automated warehousing and logistics

Cloud services are already used by over half of the participating businesses (52%). The most common reasons for this are to ensure data integrity, to provide scalable storage space and to utilize software services. Some companies also utilize the cloud to increase mobility and calculating capacities.

The most commonly used IT-systems according to this survey are CAD, ERP and CAM. The other listed systems are rarely integrated in the Oregon Forest Cluster. But there is also one third of the businesses, that utilizes none of the IT-systems. Noticeable here is the correlation between the proportion of integrated IT-systems and company size. The more employees a company has, the higher is the probability that this company utilizes at least one IT-system.

Remote servicing and maintenance are embraced by most of the respondents as 45% stated, they use this service and an additional 31% would use it if they were offered the possibility. The remaining 24% do not use remote servicing, mostly because they do not need it and maintain in house.

The evaluation of the most frequently used identification methods for materials and products shows that 1D and 2D Barcodes are still the preferred means among the interviewed businesses. Recognizing wood by its individual "fingerprint" is already becoming more popular, whereas RFID and Photo ID are probably too inconvenient and therefor are not accepted very well. The fact, that still 38% of the companies are not using any product identifiers is concerning. In the course of a proper educational initiative, the advantages and opportunities of different identification methods should be illustrated.

Interestingly, 21% are using the pay-per-use concept for machines, equipment or software. This is more than expected regarding the estimations of the interviewed experts.

Another highly digital technology is Virtual and Augmented Reality. Some of the surveyed companies (10%) already apply it, for instance for virtual reality videos for PR purposes or engineering. These are all businesses with over 100 employees.

Figure 7 displays that Robotics are not widely used yet. Eighty-six percent of the participating companies do not have any type of robotics integrated into their production, although 45% admit this would be a useful technology. Fourteen percent either integrated substituting robots, cooperative robots, AGVs or different types of robotics in their production.

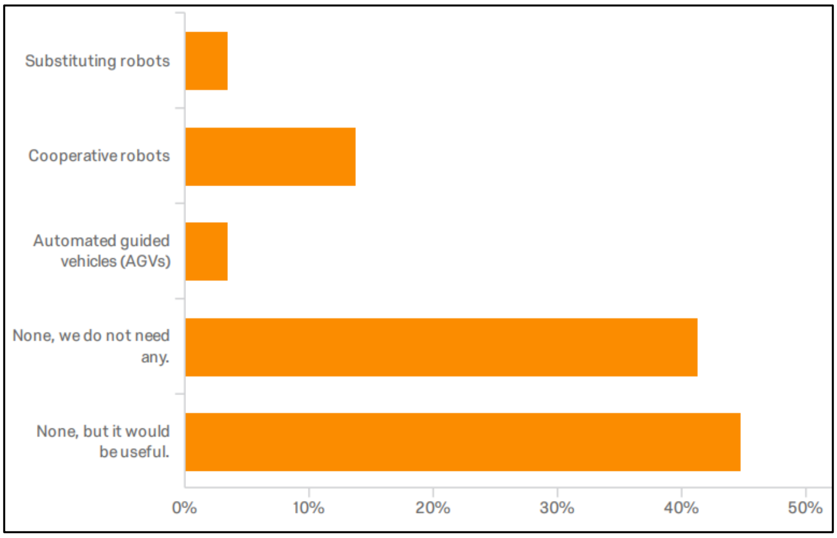


Figure 7: Use of different types of robotics

At the end of the survey the participants provided insight into their companies' plans for the future. Sixty-six percent plan to invest in new manufacturing technologies or/and techniques in the next three years. Most frequently mentioned are robotics, CNC machines and automation in general.

3.2. Overcoming Key Hurdles

The analysis of the expert opinions and the online survey presented two key hurdles for the adoption of new manufacturing techniques and technologies:

a) A lack of skilled workforce / expertise
b) Unclear (financial) benefits from an investment

Taking these hurdles is the most important requirement to enable a successful transformation of a business and, in the further course, to overcome the other difficulties revealed by the survey.

Companies stagnate if they do not have the required expertise within their workforce to adopt new technologies and there are no experts, who are qualified and responsible to push the digital advance. With a shortage of skilled labor on the market, it is not easy to hire new specialists, especially in the wood processing industry. And this may not even be the best approach for businesses as it is more sustainable to upgrade the education of their employees. Offering trainings to employees, who already know the company, ensures the best way and rate of use of already existing technology and its application possibilities, and makes them feel more confident. This also stills the fear of an implementation of new techniques and technologies. Trainings should be offered through the whole transition and the affected employees should be involved in the whole process because this is essential to build up commitment to the new machinery or software. The most important factor for a successful digital change is that the employees understand the technologies they are going to work with. Only this way the customers will be able to maintain the new systems themselves. If this is not the case, a company is likely to drop their plans out of insecurity regarding effective implementation and maintenance of new systems.

The inhibiting factor of unclear (financial) benefits from an investment in new technology can also be eliminated by appropriate trainings for responsible experts and management. Here the awareness raising measures should focus on the company as a networked system. Since the online survey showed that the majority of participants are convinced that new technologies would improve their production, but they do not know necessary details, it is important to give an explanation about the whole topic. Various advanced manufacturing techniques and technologies, including their advantages and opportunities, need to be introduced and compared describing their effects on the whole production process and financial benefits. In this way, the companies will realize the use and necessity of some of the technologies for their production as well as the increase of profit. If applied reasonable and adapted for the business, an implementation has a short payback time and compensates for the cost of downtime during the switch to the new system in a short time.

Therefore, training and educational measures are the key to a sustainable transition of Oregon's wood processing industry.

3.3. Developing a Roadmap

To develop a roadmap for a future technology strategy should be the next step towards Industry 4.0 in the Oregon Forest Cluster. As revealed by the previous chapters, the companies still need guidance for this transformation process.

The creation of a roadmap can be based on the conclusions of this research report and should include:

- educational material for the industry members on the potential value of advanced manufacturing techniques and technologies
- different methods for effective training
- outreach to assist the forest cluster in implementing Industry 4.0
- rough schedule for a successful transformation

The roadmap should be introduced by the Oregon Forest Cluster to increase the chances of reaching and including all members of the wood industry.

4. Conclusion

This research project revealed that the state-of-the art of the wood processing companies in Oregon is far below the currently available technologies. To improve their situation, the implementation of advanced manufacturing techniques and technologies is necessary. The businesses of the Oregon Forest Cluster have to accelerate their transition towards Industry 4.0 as automation and digitization become requirements to stay competitive. The key hurdles to adoption of new technologies are a lack of skilled workforce and unclear financial benefits from an investment. This general lack of awareness has to be eliminated as biggest inhibitor and the industry needs to react quickly because the next five to ten years will be crucial for companies to either take advantage of the opportunities of Industry 4.0 or lose competitiveness.

The evaluation of the online survey proved that the majority of businesses is convinced of the positive impact of an integration of new technologies in their production processes. Offering trainings to the companies in the cluster would be a logical consequence to assist them in overcoming their hurdles and implementing advanced techniques and technologies.

A possible first step into the direction of Smart Manufacturing could be FESTO's quick tool for companies to self-assess their readiness for Industry 4.0. This tool asks for some general information about the company and lets the users choose relevant I4.0 targets for their company. The identification of the maturity level is based on questions in five different assessment categories, which are evaluated and presented at the end. Additionally, the analysis includes corresponding recommendations for action. [21]

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Appendix

A. Questionnaire

Manufacturing Techniques and Technologies

Start of Block: Default Question Block

Q1 You are being invited to take part in this online survey, which is part of a research study titled "**Manufacturing Techniques and Technologies in the Oregon Forest Cluster**".
The purpose of this research is to identify the **state-of-the-art** in Oregon's wood processing industry regarding usage and knowledge of new manufacturing techniques and technologies as well as the main hurdles to adoption of these techniques and technologies.
Your participation in this survey is **anonymous** and will last about **8 minutes**.
If you have any questions about this research project, please **contact**: Professor Scott Leavengood (scott.leavengood@oregonstate.edu).

Page Break

Q2 Is your company an Oregon-based manufacturer or distributor of wood products?

- ◯ Yes
- ◯ No

Skip To: Q3 If Is your company an Oregon-based manufacturer or distributor of wood products? = Yes
Skip To: End of Survey If Is your company an Oregon-based manufacturer or distributor of wood products? = No

Page Break

Q3 In which business sector is your company operating?

- ☐ Primary wood products
- ☐ Secondary wood products
- ☐ Forestry services
- ☐ Equipment manufacturing
- ☐ Other: ________________________________

Page Break

Q4 How many employees does your company employ?

- ○ 1 - 5
- ○ 6 - 10
- ○ 11 - 50
- ○ 51 - 100
- ○ 101 - 500
- ○ 500 +

Page Break

Q5 How would you rate the infrastructure related to your company (very poor to excellent)?

	very poor	poor	neither poor nor good	good	excellent
Transportation and accessibility (roads, railway connection, distance to city)	○	○	○	○	○
Communication network, and internet availability and speed	○	○	○	○	○
Building condition	○	○	○	○	○
Energy supply	○	○	○	○	○

Page Break

Q6 Compared to other companies in the sector, how would you describe your competitive standing in each of the following (very poor to excellent)?

	very poor	poor	neither poor nor good	good	excellent
Regional Markets	○	○	○	○	○
National Markets	○	○	○	○	○
International Markets	○	○	○	○	○

Page Break

Q7 What is the level of awareness within your company regarding the following business / manufacturing technologies and techniques?

no awareness = **1** => high awareness = **5**

	1	2	3	4	5
Digital connectivity	○	○	○	○	○
Virtualization	○	○	○	○	○
Robotics	○	○	○	○	○
Big Data	○	○	○	○	○
Predictive analytics	○	○	○	○	○
Cloud-computing	○	○	○	○	○
Autonomous systems	○	○	○	○	○
Digital customer interaction	○	○	○	○	○
New business models	○	○	○	○	○

Page Break

Q8 For each of the issues below, to what extent might the techniques and technologies listed in the previous question *(Digital connectivity, virtualization, robotics, big data, predictive analytics, cloud-computing, autonomous systems, digital customer interaction, new business models)* support your company?

no support = **1** => strong support = **5**

	1	2	3	4	5
Dealing with globalization and future markets	○	○	○	○	○
Dealing with complexity	○	○	○	○	○
Reducing consumption of resources	○	○	○	○	○
Providing mass customization	○	○	○	○	○
Implementing new business models	○	○	○	○	○
Increasing flexibility	○	○	○	○	○
Minimizing errors along the supply chain	○	○	○	○	○

Page Break

Q9 To what extent do each of the following inhibit implementation of new manufacturing technologies in your company?

not at all = **1** => to a great extent = **5**

	1	2	3	4	5
Lack of general knowledge about new manufacturing technologies and techniques	○	○	○	○	○
Lack of knowledge of service providers and equipment manufacturers	○	○	○	○	○
Lack of skilled workforce	○	○	○	○	○
No roadmap for implementing	○	○	○	○	○
Current facilities out-of-date	○	○	○	○	○
Unclear (financial) benefits from investments in technology	○	○	○	○	○
Pending questions about data security, privacy and ownership	○	○	○	○	○

Page Break

Q10 Please indicate the level of expertise in your company in each of the following fields.

low level of expertise = **1** => high level of expertise = **5**

	1	2	3	4	5
IT-infrastructure	○	○	○	○	○
Data analysis	○	○	○	○	○
Data and IT safety	○	○	○	○	○
Automation	○	○	○	○	○
Robotics	○	○	○	○	○
User interfaces / Using assistance systems	○	○	○	○	○
Additive manufacturing (e.g. 3D-printing)	○	○	○	○	○
Cloud services and Big Data	○	○	○	○	○
Application of simulation programs	○	○	○	○	○

Page Break

Q11 Does your company provide employee training in any of the following fields?

	Yes	No	Intend to in future
IT-infrastructure	○	○	○
Data analysis	○	○	○
Data and IT safety	○	○	○
Automation	○	○	○
Robotics	○	○	○
User interfaces / Using assistance systems	○	○	○
Additive manufacturing (e.g. 3D-printing)	○	○	○
Cloud services and Big Data	○	○	○
Application of simulation programs	○	○	○

Page Break

Q12 Which of the following areas of your company are integrated horizontally (up and down the supply chain) and/or vertically (hierarchic)?

	Horizontally	Vertically	Both	Neither
Research and development	○	○	○	○
Production	○	○	○	○
Purchasing	○	○	○	○
Logistics	○	○	○	○
Sales	○	○	○	○
Finance	○	○	○	○
Customer service	○	○	○	○
IT	○	○	○	○
Human Resource	○	○	○	○

Page Break

Q13 Does your company collect machine data?

○ Yes

○ No

Skip To: Q14 If Does your company collect machine data? = Yes
Skip To: Q15 If Does your company collect machine data? = No

Page Break

Q14 Does your company process and analyze collected machine data to show the performance of production (Key Performance Indicators)?
Select one or more.

- [ ] Yes, for management.
- [ ] Yes, for real-time production.
- [ ] Yes, but not real-time.
- [ ] No

Page Break

Q15 Does your company use any form of Virtual or Augmented Reality?

○ Yes, it is used for: ____

○ No

Page Break

Q16 Does your company utilize cloud services for data storage?

○ Yes

○ No

Skip To: Q17 If Does your company utilize cloud services for data storage? = Yes
Skip To: Q18 If Does your company utilize cloud services for data storage? = No

Page Break

Q17 For what purposes does your company utilize cloud services?
Select one or more.

- ☐ To increase calculating capacities.
- ☐ To provide scalable storage space.
- ☐ To ensure data integrity.
- ☐ To utilize software services.
- ☐ To increase mobility.
- ☐ Other: ____

Page Break

Q18 What IT-systems does your company currently utilize? Select one or more.

- ☐ Enterprise Resource Planning (ERP)
- ☐ Manufacturing Execution System (MES)
- ☐ Supervisory Control and Data Acquisition (SCADA)
- ☐ Machine Data Logging Systems (MDL)
- ☐ Customer Relationship Management (CRM)
- ☐ Computer Aided Design (CAD)
- ☐ Computer Aided Manufacturing (CAM)
- ☐ Other: ____
- ☐ None of these

Page Break

Q19 What types of robotics are integrated in your production? Select one or more.

- ☐ Substituting robots
- ☐ Cooperative robots
- ☐ Automated guided vehicles (AGVs)
- ☐ None, we do not need any.
- ☐ None, but it would be useful.

Page Break

Q20 Does your company use any of the following operations based on analysis of process data?
Select one or more.

- ☐ Predictive maintenance
- ☐ Predictive quality management
- ☐ Performance analysis
- ☐ Automated warehousing and logistics
- ☐ Smart facility and energy management
- ☐ Data analysis for decision making
- ☐ None

Page Break

Q21 Does your company use remote servicing/maintenance?

- ○ Yes
- ○ No, but we would if we had the possibility.
- ○ No, because ____

Page Break

Q22 How does your company identify its materials / products?
Select one or more.

- ☐ 1D Barcode
- ☐ 2D Barcode
- ☐ RFID
- ☐ Photo ID
- ☐ wood “fingerprint” recognition
- ☐ Other: ____
- ☐ None

Page Break

Q23 Do your customers seek customized products?

- ○ Yes, and we offer customization possibilities.
- ○ Yes, but we do not offer customization possibilities.
- ○ No, our standard products are enough.

Page Break

Q24 Does your company apply the pay-per-use model (“leasing” of machines / products)?

- ○ Yes, we use it.
- ○ Yes, we offer it.
- ○ No, because ____

Page Break

Q25 Does your company plan to invest in new manufacturing technologies / techniques in the next three years?

- ○ Yes, the company plans to invest in: ________________________________
- ○ No

Page Break

Q26 What technologies would your company like to integrate into operations, but are too expensive?

____

____

____

____

____

Page Break

Q27 Does your company have a Smart Manufacturing or Industry 4.0 strategy?

○ Yes

○ No

○ In our company we are not familiar with these terms.

End of Block: Default Question Block