SSE Riga Student Research Papers
2014 : 1 (157)

COST-BENEFIT ANALYSIS OF M2M IMPLEMENTATION: A CASE STUDY OF A LATVIAN SAWMILL

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ISSN 1691-4643
ISBN 978-9984-842-77-6

November 2014
Riga

COST-BENEFIT ANALYSIS OF M2M IMPLEMENTATION: A CASE STUDY OF A LATVIAN SAWMILL

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November 2014

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Abstract

The aim of this research is to explore the potential of a machine to machine (M2M) technology in Latvian sawmills. The focus of the research is to analyse machinery maintenance and decision support systems. The maintenance of continuous band saw is evaluated as it is used in around 90 to 95 per cent of micro and small sawmills in Latvia.

The authors construct an M2M solution and evaluate its possible gains by using a simulation model and the net present value approach. The model is applied to a small Latvian sawmill which uses the respective type of saw. The simulation compares the existing set-up of the production process to three test scenarios. All the scenarios have the M2M solution. The authors analyse changes in machinery utilization, output quality, maintenance costs, overall productivity and labour efficiency. Afterwards the authors estimate the net present value of the proposed solution.

The findings support positive M2M effect on production process. A decrease in downtime and maintenance costs can be observed. The solution improves the productivity but has no significant effect on the quality of production. However, the overall net economic value of the technology is negative. The authors conclude that the technology is not mature enough and cannot yet be used to solve the existing maintenance practice inefficiencies in micro and small sawmills in Latvia.

Table of Contents

1. Introduction

Agriculture, forestry and fishing account for approximately 4 per cent of the Latvian GDP. These raw material industries do not create a lot of value in monetary terms. They are low in their respective value chains. Nevertheless, the number of companies operating in forestry has increased by 60 per cent (2005–2012). Now there are approximately 2,500 woodworking companies. In fact, the quality and the amount of raw materials are essential factors for entities that are higher in the wood products value chain. This is the basis for an argument that woodworking companies should optimize their decision-making procedures.

One of the latest solutions is machine to machine (M2M) technology that offers decision support for improved efficiency and productivity. For example, M2M solutions can monitor air quality in order to maintain a desirable condition of processed raw materials, maximize the usable board centimetres per log by scanning logs and respectively adjusting saws, optimize energy usage etc.

Hence the purpose of this study is to indicate the main machinery maintenance challenges of sawmills that operate in Latvia and the M2M solutions that could solve the problems associated with these challenges. The results of this study provide a useful roadmap for managers who want to make new investments in sawmills.

The authors analyse major risks and problems that occur in the process of sawmill machinery maintenance. Afterwards, the authors match the existing M2M solutions with the root cause of the most severe maintenance inefficiencies. The authors hypothesize that maintenance decision-making procedures, to some extent, can be improved by automation, real-time monitoring or other M2M approaches. A discrete event simulation with four different scenarios and the net present value (NPV) approach are used to determine the net economic value of an M2M solution. This study provides an evaluation of an alternative M2M solution that is more effective and competitive compared to the already existing decision support approaches in Latvian sawmills. Currently this type of analysis is not available. Moreover, the NPV analysis provides economic reasons for or against the M2M technology in Latvian sawmills.

Research Question:

(1) What is the net economic value of introducing M2M solutions which support decision-making process of machine maintenance in Latvian sawmills?

2. Sawmill operations

The conventional operation process of sawmills is rather homogeneous and in broad sections it does not deviate much for different size sawmills. Usually the only difference is the technological advance, for example, large sawmills have automatic log scanning while in small sawmills it is manual. In this section, the authors provide general description of a simple manufacturing process that takes place in sawmills. The process consists of seven stages and one support stage. The stages are (a) unloading and log sorting, (b) debarking, (c) sawing and edging, (d) piling, stickering and sorting,(e) impregnation, (f) drying, and (g) quality sorting, packaging and storing. The support stage involves actions with residuals from sawmills operations (Korpunen et al., 2010).

The abovementioned stages cover the scope of the research. Processes such as sales or logistics will not be analysed. In addition, the authors provide a brief explanation for the commonly used terminology of this research paper in Appendix 1. Figure 1 depicts a simplified log conversion process in a sawmill.

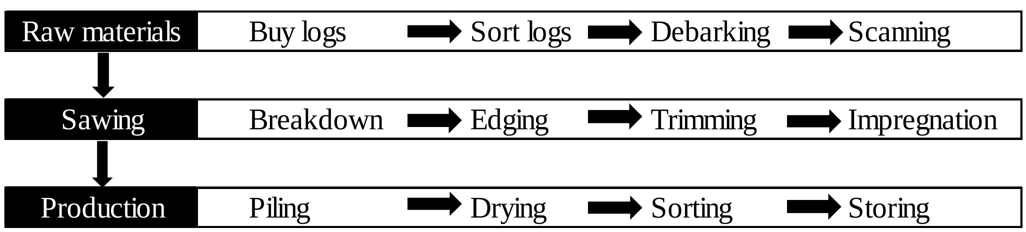

Figure 1: Log conversion process. The figure shows the basic production phases in sawmills.
Source: Created by the authors.

Stage 1: Unloading and sorting. Initially a sawmill orders and buys raw materials – logs. A sawmill then receives, unloads and sorts these logs. A sawmill makes dimensional and quality measurements for each log. Then the logs are distributed according to their quality, diameter, length and species. The logs that do not meet the requirements of sawmill production are rejected, and usually they are used for energy production or pulping. At the end of the process all logs are stored in a log yard for further processing (Korpunen et al., 2010).

Stage 2: Debarking. The next major step is log debarking. This means removing the peel or the bark together with the dirt from the log’s surface. A batch of logs is fed into a sawmill during this process. However, the logs are debarked one by one. Debarking is performed to prevent contact with sand, mud or any other debris in the next production phases, because that can decrease the lifespan of machinery and increase the speed of saw wear. At the end of this process, the debarked logs enter the sawing phase, but the bark of processed logs is used for sawmill heating purposes or sold to other enterprises (Korpunen et al., 2010).

Stage 4: Sawing and edging. The processed logs enter the sawing phase directly from the debarking phase. Usually they do not require storage between these steps. Some sawmills use scanning technology before sawing in order to assess the quality of the incoming raw material. After scanning, the logs are broken down into planks using one or more saws depending on the end product requirements. Usually planks are edged and trimmed to maintain specified dimensions. The main product during this step is planks which can be planed according to the requirements of customers. Nevertheless, during this production phase such by-products as lumber pieces, wood chips and sawdust are produced (Kailunainen, 2007).

Stage 5: Impregnation. The created material is chemically treated or impregnated in order to preserve it from environmental influence. Usually antiseptic liquids are used to prevent the planks from rotting or other biological distortions.

Stage 6: Drying. After the sawing phase, the produced planks are piled and stickered. Stickering happens by placing minor sticks in between plank layers in order to allow steady air circulation. Some sawmills at this stage also sort the planks according to their knot amount or other specifications. Diverse stickering and piling methods are used to prevent the planks from any damage, pressure marks and warping risk.

The piling stage is followed by drying process. Drying is performed to obtain appropriate moisture levels as required by the market. Two drying techniques are widely used. They are green drying and kiln drying. Green drying technique is performed by placing the sorted piles of planks in a place of steady air flow or simply in a pile. Green drying does not require a lot of input but it is harder to control and takes a longer time. Kiln drying technique is done by placing the piles of planks in closed rooms where environmental conditions are controlled by an operator. Contrary to green drying, kiln involves higher resource input. Both of the techniques are subject to strict supervision of frequent control measurements (Korpunen et al., 2010).

Stage 7: Sorting and Storing. During the final phase the end products are sorted according to their quality, as well as packaged. The piles of planks are sorted according to any damage or mistakes committed at the previous stages. The piles are packed or chemically processed to prevent any further deterioration in their quality. Afterwards the piles are stored in a warehouse and lined up for selling (Korpunen et al., 2010).

3. Literature review

This chapter offers an overview of decision-making theory issues related to machine maintenance in sawmills. Then the authors analyse maintenance issues and derive the potential impact from the flaws in maintenance procedures. Afterwards, the authors outline the technological advance in Latvia which is followed by an explanation of the M2M technology as a tool for correcting inefficiencies. The final section of this chapter provides an overview of the approaches that are usually used in the researches evaluating new decision support technologies in sawmills.

3.1. Theoretical framework

In general, there are two fields of decision-making theories. On the one hand, scholars tend to explore decisions based on different gains and benefits in terms of utility maximization. This is mainly linked with material incentives and manager rationality. However, the quickly changing market and its fast-paced dynamics have created an opposing argument. It states that human analytical power is not capable to take into account all factors and make optimal decisions (Diliberto & Anthony, 2002).

On the other hand, losses associated with each decision’s outcome are explored on the basis of minimizing costs. This field is highly linked with Prospect theory that analyses decisions based on the fact that human reactions to losses are greater compared to gains (Tversky & Kahneman, 1992). In addition, larger sawmills can sustain major increases in maintenance costs while it can jeopardize the performance of smaller ones (Al-Najjar, 2007).

Both of the previous approaches can be further divided when other factors like uncertainty, expectations, complexity, risk, fuzzy measures, resource scarcity, or time horizons are involved. In addition, other theories about line balancing or theories of constraints can be explored to foresee the manufacturing system dynamics (Cheng, 2002). Altogether, a common issue of probabilities can be indicated as the main driver for different types of decision theories.

In conclusion, as there is no best practice example of decision-making principles, different types of theories can be used to make decisions with higher success rate (Aliev et al., 2012). And decisions regarding maintenance should also include diverse information from empirical observations and current developments.

3.2. Decision support and maintenance in sawmills

Even though operations among sawmills are rather homogenous, several problems that create inefficiencies in sawmill operations management are still present. For the last couple of decades, sawmill managers have sought opportunities to tackle the existing issues. Adams & Dunmire (1977) have concluded that a sawmill manager should deal with at least six groups of issues. In general, sawmill managers focus on such things as the return and yield of each log, log conversion costs, expansion of the existing daily production, product quality, profitability, and downtime.

Each of the previously mentioned focus fields has a risk of causing inefficiencies and problems in sawmill operations. The arising problems can to some extent be limited if suitable technology is used and proper maintenance of machinery is performed. This is why managers have to make the right decisions about how and when to gather necessary measurements and make corresponding adjustments. Moreover, the data has to be collected frequently, sometimes even on a daily basis.

3.2.1. Decision-making process for sawmill maintenance

Decision-making procedures are present in every manufacturing company. Managers and operators make decisions based on information that is influenced by the quality of data. The range of decisions involves multiple stages of the company's performance where managers tend to usually deal with the strategy and long term issues. Usually it is on a daily basis that operators perform all of the necessary actions to maintain flawless production (Leana et al., 1992).

There are many problems in manufacturing with which employees need to deal immediately. However, it often takes time for an employee to either directly observe or understand from the collected data that something is wrong. When the problem has been detected, its specifics are forwarded to the management to come up with a plan how to face it. The employee is provided with guidelines for correcting the problem. Altogether the process becomes time-consuming and inefficient.

Besides complicated manufacturing decisions like investments in new technologies and strategic implications, simple daily decisions about maintenance and on-spot repairs have to be made with similar responsibility (Hakonsson et al., 2012; Kumar et al., 1996). This requires developing a comprehensive database containing daily measurements. Afterwards the data has to be compiled, stored, analysed and presented in a form suitable for the decision maker. Such tasks demand frequent supervision during which the measurements have to be verified. On top of that, some measurements face uncertainty and multi-criteria inputs that can be costly to acquire and analyse on a daily basis (Cheng et al., 2012; Zanjani et al., 2010).

Similarly to other manufacturing industries, sawmill managers and employees face decision-making procedures in their daily duties. Extensive literature covers decisions and provides solutions for log yard operations, log transportation, cost structures, scheduling process, sawing techniques, and other processes (Carino et al., 2007; Faaland & Briggs, 1984; Korpunen et al., 2010; Maturana et al., 2010; Norstebo & Johansen, 2013). In addition, simple but crucial decisions about maintenance schedule mainly are incorporated in user manuals and internal company guidelines without particular consideration.

Improper decision-making procedures for maintenance lead to considerable capital waste and cost increase. Existing literature covers maintenance cost issues stating that almost a third of the costs are wasted due to poor maintenance planning and strategies. Researchers provide models for optimizing the performance of maintenance procedures, but the decision-making process for maintenance, in general, lacks proper consideration (Dekker, 1996; Muchiri et al., 2011). Al-Najjar (2007) takes a different standpoint and, according to his views, maintenance can be a profit centre if planned cost-effectively and continuously. This only emphasizes the importance of proper maintenance schedule decisions.

There are several reasons why the decision-making process in maintenance procedures is overlooked. Some decisions, like changing blades, are trivial for managers as machine operators can do it on the spot. Still, these decisions include data about lost production time that has to be recorded. Without proper bookkeeping, the manager of a sawmill thinks that the log line is efficient and working with full capacity despite the existing costs. Sometimes managers don’t care about small decisions due to other more important issues that have already been mentioned. Researchers have explained automation potential in production lines to support small-scale decisions. Decision support systems are proposed to limit unnecessary concerns for managers giving the responsibility to machinery operators (Jensen et al., 2011; Valente & Carpanzano, 2011; Wadhwa, 2012).

Vital mistakes in decisions for sawmill maintenance lead to waste of equipment and deviations from optimal machinery usage capacity (Barone & Frangopol, 2014). For example, improper time for changing blades, inefficient change of spare parts, extended downtime, overheating of the machinery or damage to the end product. This is why it is crucial for the decision maker to obtain all of the relevant information to limit the likelihood of mistakes.

To sum up, decision-making process accounts for a substantial part of cost minimization. Decision-making procedures for maintenance issues are not properly managed. Suboptimal maintenance decisions result in wasted resources. Proper maintenance decisions require qualitative and up-to-date information about the process that has to be examined.

3.2.2. Operation maintenance

In general, maintenance can be described as a process of the preservation of essential factors that contribute to the production or any other process. Maintenance is mainly considered as a cost creating procedure that grants an entity a possibility to sustain steady production, quality, employee competence, operating environment (Al-Najjar, 2007). In addition, proper maintenance will preserve a well-developed competitive advantage even for sawmills if maintenance decisions are based on qualitative and up to date data (Li et al., 2008).

Wrong maintenance of machinery leads to an increase in production time, shorter machinery lifespan, higher expenses for replacement parts, and more breakdowns (Al-Najjar, 2007). However, maintaining optimal machinery condition requires proper maintenance. This can be achieved by using the machinery according to its specific capacity. In addition, other factors like trained operators, proper lighting, and floor space can enhance the machinery lifespan.

Due to fund saving procedures, sawmills tend to bypass the requirements for adequate labour and maintenance. Frequent maintenance procedures by competent supervisors can, to some point, limit the costs arising from machine overheating, line jams and damaged end product (Marais, 2013). Maintenance plans are mainly imposed to deal with improper controls and achieve trouble-free manufacturing performance. However, the plans only track the appointed time for inspections. Nevertheless, as maintenance problems still occur on a daily basis, the problems should be analysed and solved by the operators who have sufficient knowledge in the production process (Food and Agriculture Organization of the United Nations, 1990).

Problems in the production line or machinery maintenance lead to an increase in production time. Even though a sawmill can perform longer production cycles by exceeding machinery capacity limits, the costs can outweigh the gains from longer production cycle when a breakdown happens. There are several reasons for downtime, for example, blade changing procedures and imbalances in log flow (Adams & Dunmire, 1997).

Neglecting frequent maintenance procedures can lead to severe disruptions in operations. In the core activity of sawing, such problems as wrong saw sizes, deviations in blade alignment, saw overheating, increased tension and pressure on blades, dulled or misaligned saw teeth, or improper saw turning speed, all of which arise from decision mistakes that can be substantially limited if proper maintenance is performed (Beran, 2006; Meisner et al., 2014). The problems with saw preservation create extra costs in the form of an increase in downtime due to replacement procedures and lost value of the end product if the saw or blades are damaged (Clement et al., 2006). So appropriate maintenance is extremely important in order to prevent rising costs and lost profitability.

Besides the core activity of sawing, other parts of the log line have to be treated with a similar attention. Issues such as damaged logs on log line, improper lubrication of machinery, extensive sawdust layer on machinery, loose bearing, and over-speeding or under-speeding log line lead to increased likelihood of damage to machinery and faster machinery wear (Adams & Dunmire, 1997). Improper line maintenance with neglected control procedures leads to variation in plank thickness, shorter lifespan of saws due to cracks, and poor quality of plank surfaces.

Overall, maintenance is crucial for successful performance of sawmills. Maintenance problems have substantial impact on operation efficiency. Poor maintenance planning and procedure bypassing creates extra costs. Neglecting maintenance procedures leads to an increased likelihood of machinery breakdown, and operational problems affect the end product thereby decreasing overall profitability of a sawmill.

3.3. Operation maintenance and technological development

Operation maintenance is constantly exposed to technological development which grows continuingly. A proxy for technological development to some extent is the number of patent applications which had an average annual growth rate of 4.6 per cent during 1995-2011 (The World Intellectual Property Organization, 2012). The high number of innovations and patents provide managers with numerous opportunities in which to invest.

The process of keeping up with this trend is challenging, and managers have to evaluate and decide which technologies to acquire in order to improve their business operations. In addition, technological progress is important not only at the company level but also at the state level, because technological advances are one of the factors that can increase the overall productivity. Governments have responded to these developments by establishing authorities that deal with technology issues. For example, the USA, a country that responded early to the tech-trend, established the Office of Science and Technology Policy in 1976. One of the latest indications that technology still is an important section on governments' agendas is the creation of the European Institute of Innovation and Technology in 2008 by the European Union (The European Institute of Innovation and Technology, n.d.).

The government of Latvia has not been as proactive as the USA or the European Union. Empirical evidence suggests that this is a common situation in such developing countries as Latvia (Seck, 2012). A considerable part of the research and development in developing countries is the technology transfer from mature economies. Moreover, higher international trade activity greases the wheels of the transfer of technology (Cameron et al., 2005). Therefore, very open developing countries can to some extent outsource technological progress.

Latvia is a country with an open economy that has high levels of exports and imports relative to its GDP. Latvia is also among the EU countries with relatively high forest area to the total land area. In addition, the biggest export industry in Latvia is woodworking. This industry accounts for approximately 20 per cent of Latvia's exports each year (The Central Statistical Bureau of Latvia, n.d.). So in the woodworking industry, technology transfer could be relatively larger than in other industries as the woodworking industry might have a high information spillover effect regarding new technologies.

To sum up, one of the most important productivity drivers is technological progress, which also puts pressure on operations management. Very open economies have relatively higher technology transfers. Developing economies have higher information spillover effect regarding new technologies from other economies. Woodworking industry is an important part of the economy of Latvia. This industry is one of the most open industries in Latvia. Thus, it might have a high demand for information that reveals what kind of state-of-the-art technology is worth acquiring.

3.4. Machine to machine (M2M)

There are numerous ways how organizations can obtain information that is necessary in their day-to-day operations and decision-making processes. Process automation is widely used to collect the required data by employing advanced software. However, recently M2M, also known as "the internet of things", has extended the scope of a few information resources (Chui et al., 2010). M2M has had a major impact on information that can be obtained from the physical world.

M2M is a new communication technology which has grown rapidly due to the decreasing costs of data transmission via cellular and other networks. According to Dhraief et al. (2013), M2M is a process during which data transmission and appropriate responses within a network of devices can be executed without human interference.

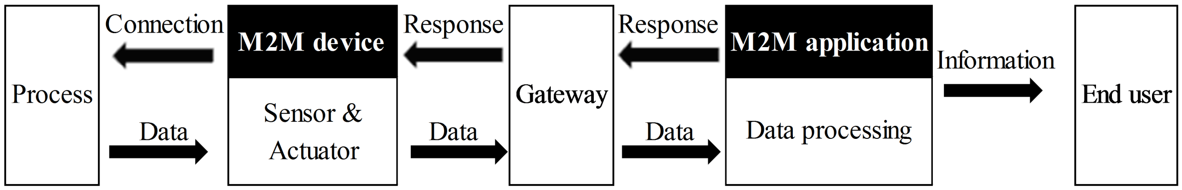

Figure 2: The basic steps and resources that are integrated in M2M processes.
Source: Created by the authors using information from Dharief et al. (2013).

Figure 2 depicts how M2M technology works in a general case. First, a management team has to decide which process and factors should be monitored. For example, wood drying process with such factors as the level of temperature in a kiln and the moisture content of wood which has to be dried. Then an M2M device is connected. This device gathers data about temperature and moisture and sends it to a gateway. The gateway acts as a moderator which distributes the data to a corresponding M2M application. Next, this M2M application receives the data and processes it. The data gets analysed and it is either delivered to an end user or some information is sent back to the M2M device (Dhraief et al., 2013). For example, the M2M application analyses information about the moisture and sends back information that contains guidelines for how the M2M device should adjust the level of temperature in the kiln.

In 2004, first articles about M2M communication technology appeared. Since then, numerous analysts have forecasted high growth rates in the M2M market. The size of the market will be close to 750 billion EUR by the end of 2020, while in 2010 it was only 87 billion EUR (The Economist Intelligence Unit, 2012). Scholars and business practitioners have now acknowledged the importance of M2M. Nevertheless, many of the previously observed M2M growth rates have not met the expectations.

Manyika et al. (2013) estimate the potential of M2M in manufacturing. They argue that 2.5 to 5 per cent of the total operating costs in manufacturing processes will be saved if M2M is introduced. Furthermore, their forecast about manufacturing processes shows that the global M2M adaption rate will be 80 to 100 per cent by the end of 2025. Chui et al. (2010) identify six main areas where M2M applications might have positive influence. Applications that are relevant to sawmills are sensor-driven decision analytics, process optimization and efficient resource consumption. The other three are monitoring of behaviour of different things, enhanced situational awareness and complex autonomous systems.

In response to the latest M2M developments, Ferber (2013) urges managers to tackle the challenges brought by M2M. If organizations are not flexible enough to adapt, they will have major difficulties in securing their competitive advantages while facing increasing competition. Moreover, Ferber (2013) suggests that environment will become more dynamic due to M2M innovation, and some manufacturing companies will have to integrate service-based business models into their strategies. Allmendinger & Lombreglia (2005) have an even more radical opinion. In their Harvard Business Review article, they state that product-oriented business models will become obsolete in manufacturing.

Chui et al. (2010), Ferber (2013) and Allmendinger & Lombreglia (2005) see great potential in M2M. Nonetheless, they do not consider the drawbacks of M2M. In reality, the technology is not a panacea. The authors of the research consider the challenges that the M2M technology faces. These challenges are data security, mismatch between growth of information and organizations' analytical capabilities, optimal architecture of M2M systems, and segmented and non-standardized market.

Decision makers have a lack of awareness about M2M (The Economist Intelligence Unit, 2012). Manyika et al. (2013) also point out the same issue. They emphasize that the M2M technology has not yet matured and its costs have not achieved a competitive level. The M2M technology has already been explored in the communication sector, touching upon manufacturing as well. Nevertheless, researches focusing on profitability or other key performance indicators in manufacturing have only been partly considered M2M (Evans-Pughe, 2013; Stenumgaard et al., 2013). This can also be stated about the woodworking industry due to a lack of discussions regarding M2M in academic journals.

To sum up, the authors agree with the general view that there is a growing interest about M2M in the business world. However, most of the authors focus on benefits that M2M can offer to businesses. There is a lack of solid analysis and evidence about the true costs and the true risks associated with M2M technology at this stage. Nevertheless, business consultants and market analysts point out that manufacturing industry will have high M2M penetration rates. Besides, M2M applications that have an effect on optimization and cost reduction will have the highest growth rates. Sawmills might reap a lot of benefits because they have relatively standardized operations. In addition, any new M2M breakthroughs in this industry can have major improvements in sawmill operations that can be relatively easy to transfer from one enterprise to another.

3.5. Technology implementation costs

As mentioned in the previous section, M2M has the potential to successfully ease the required planning and data acquiring process for sawmill maintenance decisions. However, similarly to other new technologies that could be implemented in the daily operations of sawmills, evaluation methods significantly lack exploration of cost impact. This to some extent can be explained by the changing costs as the market starts to adapt the new technology.

When looking at the implementation of new technologies, the emphasis usually is on the potential benefits while the costs are left outside the research scope. Widely explored example is log scanning technologies that help to detect any disturbances in logs and support decisions of how to maximize the output. Numerous researchers analyse different efficiency and optimization gains when a scanning technology is used to acquire data for more efficient decisions (Chiorescu & Gronlund, 2000; Moberg & Nordmark, 2006; Smith et al., 2003; Seger & Danielsson, 2003). The researches mainly lack sufficient emphasis on initial investment, running costs and maintenance costs of new technologies.

In conclusion, consideration of new technologies also involves cost estimates. Current researches on sawmills focus on the utilization of the benefits of new technologies. There is a gap in the existing literature for cost evaluation of new technology implementation.

4. Methodology

This research analyses a single sawmill by exploring its inefficiencies in maintenance practices and linking them to the sawmill industry. M2M technology is then considered as a tool to correct the spotted inefficiencies. Hence, M2M implementation in the existing sawmill operations is the unit of analysis. The authors provide a methodology that incorporates a flexible simulation model. Moreover, it provides an overview of the costs and benefits of M2M implementation. The authors hypothesize that maintenance decision-making procedures can to some extent be improved by automation, real-time monitoring or other M2M solutions.

A combination of cost-efficiency, simulation and net present value analysis is the approach how to confirm the authors' proposition. The chosen approach takes into account M2M project implementation costs and potential benefits. As already mentioned, scholars usually focus on the benefits that some new technology can provide. Thus, this research provides more comprehensive overview for decision makers in sawmills and M2M engineers.

4.1. Data collection and description

The authors develop a M2M solution for the sawmill "Anipsis". Different types of data are retrieved to find out what kind of devices should be combined in the M2M solution. Operational and financial data are obtained from the sawmill to find out the existing cost structure and operational performance of "Anipsis". Additionally, the authors obtain data about M2M from companies operating in M2M market. The M2M data consists of the implementation and maintenance costs together with other relevant specifications. The general aim of the data collection process is to understand suboptimal processes and risks in the sawmill operations and then find potential solutions using data about the M2M technology.

Qualitative data about the sawmill is obtained from an interview and documents provided by the manager of "Anipsis". During the interview, descriptive information about the sawmill was obtained together with key observations. The main focus during the interview was to explore the existing maintenance procedure and support systems. The maintenance procedure focuses on the ways how machinery is maintained, who performs it and how much time does it take. The existing support systems are explored by analysing their level of automation and responsiveness to changes in maintenance practices. In addition, the manager presented key performance indicators, such as raw material turnover and sales for the last three years.

The authors used ORBIS database to explore M2M companies. The ORBIS database contains financial, legal and other information about public and private companies worldwide. The authors obtained a list of 755 companies from the database using keywords associated with M2M.Then the authors selected 66 companies that met geographical and operational criteria. The benchmarks were companies that have operations in Europe and those that exceeded 71,875 EUR in sales in 2012. The year 2011 was the latest available in the database.

The authors browsed the selected companies' web sites for off-the-shelf M2M solutions. This phase was followed by electronic correspondence and interviews with sales representatives from global M2M engineering companies, such as “Micro-epsilon”, “SMC” and “Banner Engineering”. The retrieved information covers technical specifications, benefits, risks, and costs of the proposed M2M solution (Appendix 2). Moreover, the authors obtained device manuals in order to explore the complexity of the initial set-up and maintenance of the M2M solution.

In the sawmill, several measurements of efficiency are not recorded automatically and initially they were not available. Thus, the manager was asked for a month to collect data about the number of times blades hit debris. Throughout one month, 16 events of blade hitting debris were reported. In addition, the authors conducted a three day field work to collect efficiency and productivity estimates by observing the production process and measuring the time spent at the production phases. A part of the collected data during the field work and a part of the data provided by the manager is presented in the Appendix 5. In addition, field work observations are used to confirm the manager's statements about maintenance practice and operational performance in the sawmill “Anipsis”.

The authors use ORBIS database to compare the sawmill “Anipsis” and the woodworking industry in Latvia. Such parameters as profit before tax, turnover, total assets and profit margins were retrieved for 2,413 Latvian woodworking companies for the last three years. In addition, data about the presence of continuous band saws in micro and small sawmills is retrieved from an interview with a continuous band saw distributor. The authors present the saw used in “Anipsis” in Appendix 13. Other data such as the date of establishment and the number of employees of these companies were retrieved to explore the general similarities between the sawmill “Anipsis” and the industry.

4.2. Methods

Primarily, the improvements in maintenance practices are introduced in order to reduce costs while increasing overall efficiency. In addition, an increase in production quality can also be among the reasons why maintenance should be improved. Thus, the contributions that influence the effectiveness of maintenance are evaluated based on the cost-effectiveness of an investment or a bundle of investments. In the research, the authors propose an investment in an M2M technology that can improve the maintenance practices in the sawmill “Anipsis”. The M2M technology and a full solution are described in the analysis part of this paper.

The authors analyse the operational cost structure of “Anipsis” in order to compare the production costs before and after the M2M solution. The analysis of production costs before the M2M solution is based on data which was obtained from the sawmill “Anipsis”. After introducing M2M, the potential costs and benefits of the M2M solution are estimated using the information from a sales representative of “Micro-epsilon” and websites of M2M companies. The authors estimate the benefits according to the technical and financial factors that are affected by possible improvements in machinery maintenance.

4.2.1. Simulation model

An interaction between the M2M solution and the production process is simulated by modelling the ways how it can affect the operational costs and benefits in the sawmill “Anipsis”. Simulation is required because some variables have standard deviations and randomness. In addition, the true distributions for some variables are unknown. Based on the sawmill process that was introduced in the chapter “Sawmill operations” and data about “Anipsis”, the authors developed a simplified discrete event simulation model using software Stella 9.0.1.

The model is a simplification of the operations that take place in the sawmill in reality. The focus of the model is to depict the work of production machinery in sawmills and the effect that M2M may have on production time and costs. In Appendix 4, the authors provide simulation’s Stella code for the Base scenario. A diagram of the model is presented in Appendix 3. The simulation aggregates a number of resources that are used during the production process and converts them to monetary units. The results of the simulation help to understand changes in the following key performance indicators when the M2M solution is integrated in the production process.

In this research, the main identified bottleneck with important maintenance issues is the saw that cuts logs into planks. The saw also accounts for a vast amount of the maintenance costs in approximately 90 to 95 per cent of the Latvian sawmills. Due to the saws significance in the production process, further on only the usage of the continuous band saw will be discussed.

In the model, any improvement in business operations can come from different sources. Here the sources area better timing of maintenance tasks or some improvements in problem finding approaches and a faster root cause detection (Al-Najjar, 2007). A positive impact on technical and financial factors will be achieved if there are positive changes in at least one of the sources. The authors present a list of technical and financial factors that was developed by Al-Najjar (2007). The list includes downtime, changes in quality and changes in maintenance costs.

Technical factors

- Downtime

$$S_1 = PT_1 - PT_2 \tag{1}$$

$$PT_1 = C_x \times C_t + H_x \times H_t \tag{2}$$

$$PT_2 = C_{xM} \times C_{tM} + H_{xM} \times H_{tM} + \Delta X \tag{3}$$

S_1 shows possible benefits from a decreased downtime within some period of time. $PT_1$is the downtime for a production process without the M2M solution; however, PT_2 is the downtime for a production process with the M2M solution.

C_x denotes a certain frequency of cleaning blades of the saw. The authors use interviews and observations in the sawmill to obtain a point estimate for C_x. C_t represents the time that is spent on cleaning the blades. This estimate is obtained in the same way as C_x.

H_x denotes a certain frequency of changing damaged blades. The authors use interviews and observations in the sawmill to obtain a point estimate for H_x. H_t represents the time that is spent on changing the blades. This estimate is obtained in the same way as H_x.

ΔX is a change in sawing precision between two models, one without the M2M solution and the other with the M2Msolution.The change in sawing precision is present because the M2M solution can track deviations in the alignment of saw. In addition, the M2M solution automatically cleans the blades. An optimal alignment can limit sawing mistakes while the automatic cleaning improves the surface of planks by making it smoother. In the model with the M2M solution, the precision factor increases and changes the production time. In the model without the M2M solution, this factor is assumed to be constant and it does not bring extra variability in the production time. The value of ΔX depends on a scenario of simulation. The scenarios used in this research are available in Appendix 5. But the general relationship between the sawing precision and time is positive, when the precision of sawing increases the sawing time also increases.

Financial factors

- Change in quality

$$S_2 = Q_{1st} \times P_{1st} + Q_{2nd} \times P_{2nd} + F \times P_F \quad (4)$$

$$Q_{1st} + Q_{2nd} + F = raw\ materials = 100\% \quad (4.1)$$

S_2 shows the monetary gains from one cubic metre of logs according to sawing quality. In the analysis, S_2 is a relative measure between base and the other scenarios. Q_{1st} is the Class 1 production before and after the introduction of M2M in the operations. Q_{2nd} is the Class 2 production before and after the introduction of M2M in the operations. F is the firewood and by-product production before and after the introduction of M2M in the operations. The authors use an interview and data provided by the sawmill manager to find out point estimates for the abovementioned factors.

The sawmill's products are expressed as a percentage of raw materials. The M2M solution can change the precision of sawing, thus, it can also increase the Class 1 production and decrease either the Class 2 or the firewood production. However, an increase in the precision can increase the sawing time.

P_{1st}, P_{2nd} and P_F are the selling prices for each type of production. The prices are obtained from the web site of the sawmill "Anipsis". The simulation model is simplified so that only one price rate is applied for each production type, although in reality the prices are determined also by other factors. This variety of prices can be observed due to seasonality, wood types, humidity levels, specifications and dimensions, deviations in demand etc. All of these factors are left outside the scope of the research paper because they do not significantly influence maintenance practices.

- Change in maintenance costs

$$S_3 = M + \Delta H \times W + \Delta C \times W + \Delta A + \Delta U \quad (5)$$

S_3 shows the difference in maintenance costs between a production process without the M2M solution and a production process with the M2M solution. The maintenance costs in this model are limited to the operational costs of the M2M solution (M) and the costs that are associated with the cleaning of the blades ($\Delta C \times W$) and the changing of blades ($\Delta H \times W$). In addition, there are changes in blade sharpening costs (ΔA) and in the number of blades used within some period of time (ΔU) due to introduction of M2M. In the analysis, S_3 is presented as a relative difference between the base and the other scenarios. The authors obtain estimates for these variables using interviews together with operational and financial data provided by the sawmill manager.

W is the hourly wage rate in the sawmill. It is not variable and is obtained via an interview with the sawmill manager.

ΔH is a change in the time that employees spend on changing the blades.

$$\Delta H = H_x \times H_t - H_{xM} \times H_{tM} \quad (6)$$

ΔC is a change in the time that employees spend on cleaning the blades.

$$\Delta C = C_x \times C_t - C_{xM} \times C_{tM} \quad (7)$$

Performance factors

- Average maintenance costs (EUR) per month

This is an indicator which takes into account all maintenance costs, for example, saw maintenance costs, truck maintenance costs, sharpening costs, spare parts etc. The indicator is linked to the simulation via Equation (5), change in maintenance costs. Maintenance improvements do not touch upon truck maintenance. It still creates costs but in this research they are constant. Thus, they are excluded from Equation (5). The equation is described in the chapter “Financial factors”.

- Average minutes worked per day

The average minutes worked per day is a proxy for productivity. It sums all the minutes that are spent on producing output without maintenance. Stoppages, which are not related to the production process, such as lunch breaks, employee arrival times or other pauses are outside the scope of this research. The average minutes worked per day is linked to the simulation via the downtime in Equation (3). An increase in the average minutes worked per day leads to higher utilization of the production line.

- Productivity

The productivity ratio is described as an output relative to inputs in monetary terms. Simulation results influence both parts of this ratio. The output is influenced by Equations (1) and (4) but inputs are influenced by Equations (1) and (5). The equations are described in chapters “Technical factors” and “Financial factors”.

- Changes in production quality

The ratio shows the value of production. It is based on Equation (4).

4.2.2. Scope of the model

The analysis of the model is limited to the production phases that have a link to maintenance decisions. In addition, these decisions have a significant effect on operational performance. The model focuses on inputs and outputs that can be affected by the M2M solution in an average sawmill. For example, the authors exclude the variables relevant to kiln drying because an average Latvian sawmill does not use this type of drying technology. Thus, the model in general is a simplification of the production process in sawmills. A list of model’s assumptions and simplifications are presented below.

4.2.3. Business processes

In sawmills, other business processes such as sales or supply chains have very low maintenance costs. In addition, the proposed M2M solution is unsuitable with such maintenance. That is the main reason why the scope of the model is limited to the production process.

Raw materials

The scope of the model deals only with one particular type of raw materials. One size (length = 6 m; $diameter_1$ = 0.19 m; $diameter_2$ = 0.34 m) pine logs are fed in the sawmill. In addition, there is unlimited amount of logs in the stock, and all the logs have the same qualities.

Raw materials is a significant cost driver in sawmills. It is important to properly store the stock of raw materials to maintain their quality. However, the M2M solution is not developed for this process since the storage space is the main solution for that kind of problem.

Production

The model simplifies the way how logs are processed into end products. The sawmill manufactures only three products (Class 1, Class 2 and firewood), and their dimensions are not simulated. Thus, the products are not expressed as a number of planks; the measurement of the products is a percentage of processed logs. Moreover, it is assumed that all by-products such as woodchips, sawdust and bark are classified as the firewood production.

Production stages

The general production process is also simplified. Not all activities are depicted in the model. However, time, human and monetary resources are accounted in other activities. For example, the "Enter sawing" stage in the model accounts for picking up logs and delivering them to the production line.

Main assumptions

The authors create several assumptions for the model to simplify the production process in sawmills and control for uncertainty. The assumptions are:

1. The only downtime occurs due to maintenance and sawing failures.
2. The model assumes normal distribution for the variables when their true distributions are unknown. The list of such variables is presented below.
    a. Number of events when the blade of the saw gets damaged when it hits debris.
    b. Number of logs sawed and trimmed per hour.
    c. Time spent on impregnation.
3. The performance of the sawmill is not influenced by external factors such as force majeure, electricity costs etc.
4. All by-products are classified as the firewood production.
5. The M2M solution does not make the production process less effective as it is.

4.2.4. Verification and validation

Kleijnen (1995) summarizes theoretical and methodological perspectives of verification and validation in operations research. The authors use modular testing approach to verify the simulation model. Firstly, the authors debug a simplified version of the simulation. The simplified version is the basic production process in the sawmill. Secondly, the authors manually estimate simulation outputs and match them with the model's results. Student's t-test specifies the difference between simplified simulation's outputs and expected values. The authors use Student's t-test because simulation variables reply in a pattern that is similar to normal distribution (Kleijnen, 1995). More complex parts such as M2M specifics are added to the model only after the abovementioned steps.

The authors use real-world data and the interview with the manager of "Anipsis" to validate the model. Model's outputs have to match the operational performance of "Anipsis" when the authors use real-world data as inputs for the model. In addition, the authors use sensitivity analysis because some of model's variables cannot be observed in the real-world. For instance, the true link between M2M and its effect on production quality might be ambiguous. Thus, the authors validate the model by changing different production inputs and the characteristics of the M2M solution (Kleijnen, 1995).

4.2.5. Investment evaluation

The authors develop four simulation scenarios in order to analyse the performance of the M2M solution. One is the base simulation which models the operations as they are in real life in the sawmill "Anipsis". The second simulation uses realistic scenario which combines the base simulation and the M2M solution with the base inputs. The third simulation has an optimistic scenario. It is similar to the second simulation scenario but, instead of the base inputs, it predicts a lower standard deviation in output due to M2M. The fourth simulation also combines the base simulation and the M2M solution. However, it predicts a higher standard deviation in output due to M2M. Differences in scenario inputs are presented in Appendix 5.

The key performance indicators are compared based on all simulation results. This kind of approach also allows the authors to test the sensitivity of the simulation model. In addition, after implementing the M2M solution in the three simulation scenarios, the authors apply the net present value (NPV) method to determine the economic potential of the M2M solution.

$$PV(i,N) = \sum_{t=0}^{N} \frac{netCF_t}{(1+i)^t} + PV(tax\ shield)_t \tag{8}$$

In order to calculate the NPV, the authors determine the costs and benefits for the M2M solution during their useful lifespan. The necessary information is acquired from anM2M sales representative and the simulations. In addition, the authors calculate the tax shield of the investment. Afterwards, the authors calculate the net cash flow of this investment according to its benefits and costs. That is denoted as $netCF_t$ in Equation (8) for each year (t). N is equal to the warranty period of the M2M solution. The period is expressed in years. i is the discount rate of this project. In order to calculate the value of the discount rate, the authors use estimates suggested by Damodaran (n.d.). More precisely, the authors use the estimates that apply to companies working in paper and forest industry in emerging markets. Since different risks across different emerging economies are not homogenous, the authors also adjust the rate for specific risks in Latvia by including country specific currency risk and default risk.

The authors test NPV model's sensitivity because the information about the true risks associated with "Anipsis" might suffer from inefficiencies. That means that the discount rate estimate might deviate from the true discount rate. Thus, the authors calculate realistic, optimistic and pessimistic discount rate and obtain a range of possible net economic values of the whole project.

5. Analysis

In this chapter, the authors present the analysis of the sawmill "Anipsis". In the beginning, the authors describe the production process in the sawmill. Also, the sawmill is compared to other micro and small sawmills in Latvia. Then the authors analyse the existing maintenance decisions procedures in the sawmill. This is followed by a description of the M2M solution proposed by the authors. Further sections provide information about the simulation results and their implications. In the end, the net present value of the M2M solution is carried out.

5.1. Production process in "Anipsis"

The operations in "Anipsis" follow the standard phases presented in "Sawmill operations". The main specifics are described further in this paragraph. The sawmill uses only one log cutting saw. Two operators control the inflow of raw materials, sawing and the outflow of production. In addition, they are responsible for maintenance decisions and execution. The authors create an M2M solution for the saw, which is also the core machinery. An extra employee is responsible for sharpening and bending blades. Another employee impregnates and stacks the production. The sawmill uses the green drying technique.

5.2. The sawmill "Anipsis" and the woodworking industry

"Anipsis" is a micro and small size sawmill in Latvia. Approximately 90 to 95 per cent of all micro and small sawmills use the continuous bend saw as confirmed by the particular saw distributor "Tehnika Auce". This type of saw is used by "Anipsis" as well. Micro enterprises employ up to 9 employees and small enterprises employ up to 49 (Ministry of Economics of the Republic of Latvia, 2014). There are 2,413 woodworking companies registered in Latvia (NACE code 16.10), micro and small enterprises account for 95 per cent. "Anipsis" and 929 other sawmills employ up to 10 people.

In the obtained sawmill sample, micro and small sawmill turnover is up to 1,500,000 EUR per year. "Anipsis" had a turnover of 44,000 EUR in the year 2013. Profit margin for the woodworking industry in 2013 was on average negative, however, "Anipsis" had a net profit margin of 5.12 per cent.

5.3. Maintenance decision analysis

On average, "Anipsis" spent 2,052.81 EUR on maintenance-related activities in 2010-2013. That accounts for 9 per cent of all expenses excluding raw material costs. In this case, maintenance related expenses are a significant cost driver. For example, a 20 per cent decrease in maintenance costs could increase the operational profit by 16 per cent.

Despite the abovementioned analysis, the sawmill "Anipsis" does not have an effective maintenance decision procedure with suitable support systems. Simple but very important decisions are incorporated in user manuals and maintenance guidelines. However, they are not fully analysed before the incorporation. For example, the timing of blade changes is based only on manufacturer's suggestions. In addition, the sawmill manager has not set any performance indicators for maintenance decisions.

The quality of a maintenance decision depends on saw operators' experience and analytical skills as they are responsible for the saw maintenance in the sawmill "Anipsis". The operators make decisions on-spot but a considerable amount of data gets lost. For example, such data as lost production time, the effectiveness of the previous maintenance decision and output quality changes are not recorded. In general, maintenance decisions are taken in a timely manner but the decision quality is not evaluated. It is mainly influenced by external experts who do not know the specifics of the sawmill production process. In addition, a lot of important data is not codified.

Overall, the sawmill does not have a maintenance strategy. The data and information about maintenance is explicit knowledge. Nevertheless, a database with daily or monthly measurements about maintenance decisions is not available. Moreover, a support system, which could verify the data and measurements, is absent. All these problems cause inefficiencies and extra maintenance costs that will be analysed further.

5.4. Description of the M2M Solution

The M2M solution consists of 5 off-the-shelf electronic products (Appendix 2). Connectivity is set up between five devices. The initial investment for purchasing all five devices, their mounting parts and connection wires is 725.50 EUR. This is the lowest cost that can be obtained for a solution that can effectively operate under harsh environmental conditions such as temperature changes, humidity and others. The overall price can vary as the market prices for the devices can change. The investment can also be lower or higher depending on what kinds of connection type is used.The types can be either cables or wireless. Wireless connection can face problems of blocked signal by disturbances while cables can be physically damaged. Main reason against wireless connection is its inability to provide electricity supply for the devices. This is why only cables are considered further in the paper for connecting devices.

The process begins with the laser reading the distance from a sensor to the blade surface. The laser in this system is the sensor that was depicted in Figure 2 in chapter “Machine to machine (M2M)”. The distance to the blade is fixed to some calibrated length upon initial set-up. This corresponds to the process that the sensor is measuring. After the first test runs, the distance is recorder by software, which can execute the processing of such data. The signal from the laser is converted to a computer code and processed in the software.

The laser can detect any deviations in the distance. Such deviations can indicate that the blade has been bent because of some debris, significant sawdust layer has appeared, or the blade has been wrongly mounted. In the current maintenance practice, the saw has to be stopped to clean the blade surface. As the laser has detected deviation from the optimum distance, the first signal from the data processing software is sent to an electronic valve which opens a stream of cleaning fluid.

The electronic valve together with an alarm indicator can be perceived as actuators. If the laser continues to read deviations from the optimum distance, the alarm will go off. In that case, the saw operator has to make adjustments or change the blade..

The M2M solution provides different benefits to the existing maintenance practice and the production process. With the electronic valve, the cleaning of blades is automated, thus, there is less downtime. The automation also allows the production process to have fewer flaws. In addition, the proposed system can be utilized to gather and store the data about stoppages. The software also serves as a processor providing information to the manager.

5.5. Simulation results

In total, 50 simulations are performed for each scenario with the previously explained inputs (Appendix 5). The variables of the simulation are observed in 15 minute intervals, meaning that each variable is obtained 706 times throughout one simulation. Every log has its own unique ratio between the Class 1 and Class 2 production and the firewood production. The presence of debris and the events of blade cleaning and changing are recorded as dummy variables. At the end of the simulation, the total number of such events is recorded. The authors calculate the average values of all the variables. The average number of blade changes is presented in Table 1. Other averages are presented in the following tables.

Averages	Unit	Scenario			
		Base	Realistic	Optimistic	Pessimistic
The average number of blade changes	times	104.5	100.24	98.94	101.22
Standard deviation	times	3.86	3.67	3.23	3.01

Table 1: The average values of blades changed during each scenario.

Source: Created by the authors.

In the Base scenario, on average the blade is changed 104.5 times. By introducing the M2M solution, this number can be decreased at least by three times. Such development increases the sawing time by 18 minutes every month. In all simulations, on average 16 changes are performed due to damage to the blade caused by rocks or other debris.

5.5.1. Statistical significance

Significance of the simulation results is based on Student's t-tests for several variables. It is tested in three parts: the average production of Class 1, Class 2 and firewood, the production ratio of Class 1, Class 2 and firewood, and the average maintenance time. The tests are performed between the Base scenario and the other scenarios with the M2M solution. In addition, statistical significance is also tested between the scenarios with the M2M solution. In general, simulations with different scenarios are statistically significantly different from each other on average. However, some variables are not statistically significantly different between the scenarios. An overview of all t-values is presented in Appendix 6.

5.5.2. Downtime effect

In the research, downtime appears only due to cleaning or changing the blade. In Table 2, the authors provide the average downtime results from all scenarios.

Change in downtime (S1)	Unit	Scenario			
		Base	Realistic	Optimistic	Pessimistic
Total downtime	Minutes	980	602.82	594.33	609.38
Change in downtime (% of Base)	per cent	100.00	**-38.49%**	**-39.35%**	**-37.82%**

Table 2: Change in downtime (S1).
Source: Created by the authors.

A considerable change in the downtime comes from the eliminated blade cleaning time. Every scenario with the M2M solution gains 353 minutes of sawing time as there is no need to stop the saw for cleaning. Other changes in the downtime appear due to fewer stoppages for changing the blade.

There is a statistically significant difference between the simulation scenarios when the downtime variable is tested. The scenarios with the M2M solution have statistically significantly different average maintenance time compared to the Base scenario. Similar results are observed for differences between the scenarios with the M2M solution. Overall, the M2M solution has a major impact on the downtime. The downtime on average can be decreased by 38.49 per cent in the Realistic scenario, 39.35 per cent in the Optimistic scenario, and 37.82 per cent in the Pessimistic scenario.

5.5.3. *Quality effect*

The M2M solution influences the sawing precision which is an important factor for the Class 1 and the Class 2 production. Improvements in the precision can increase the sawing time for one log. That happens due to the fact that adjustments have to be performed more often. The M2M solution increases the precision by detecting deviations from the initial set-up. The results for changes in quality are presented in Table 3.

Change in quality (S2)	Unit	Scenario			
		Base	Realistic	Optimistic	Pessimistic
Class 1 output from one m^3	per cent	26.74	27.02	26.95	26.97
Class 2 output from one m^3	per cent	23.12	23.03	23.01	22.91
Firewood output from one m^3	per cent	50.14	49.95	50.04	50.12
Change in the Class 1 output	per cent	-	0.28	0.22	0.23
Change in the Class 2 output	per cent	-	-0.09	-0.12	-0.21
Change in the firewood output	per cent	-	-0.19	-0.10	-0.02
Output from one m^3 of logs	euro	103.37	103.78	103.62	103.53
Change in output value (% of Base)	per cent	100.00	**+0.40%**	**+0.24%**	**+0.16%**

Table 3: Change in quality (S2).
Source: Created by the authors.

In the Base scenario, one cubic metre of logs creates output that is worth on average 103.37 EUR. The results suggest only marginal increase in the value of the monetary output per one cubic metre of logs. Relatively to the Base scenario, the M2M solution increased production value on average by 0.4 per cent in the Realistic scenario, by 0.25 per cent in the Optimistic scenario, and by 0.17 per cent in the Pessimistic scenario.

T-values for production show that there is a statistically significant difference between all the scenarios with the M2M solution and the Base scenario. However, t-test values are insignificant between the scenarios with the M2M solution. Thus, the simulation results are not statistically significantly different in terms of Class 1, Class 2 and firewood quality among the simulations with the M2M solution (Appendix 6).

5.5.4. *Maintenance cost effect*

The maintenance costs that change during the simulation are wages paid to employees for cleaning, changing and sharpening blades, the expenses associated with the M2M solution's maintenance, and purchases of new blades. Costs associated with the downtime are reduced due to the M2M solution. In Table 4, the authors provide the results of maintenance cost effect.

Change in maintenance costs (S3)	Unit	Scenario			
		Base	Realistic	Optimistic	Pessimistic
Blade changing costs (per month)	euro	20.20	19.38	19.13	19.57
Blade cleaning costs (per month)	euro	11.37	-	-	-
Costs of M2M solution (per month)	euro	0.00	1.83	1.83	1.83

Blade sharpening costs (per month)	euro	134.67	129.27	127.60	130.54
New blades purchased (per month)	euro	3.36	3.23	3.19	3.26
TOTAL	euro	169.60	153.71	151.74	155.19
Decrease in maintenance costs per month	euro	-	**-15.89 €**	**-17.86 €**	**-14.41 €**
Decrease in the total costs (% of Base)	per cent	100.00	**-9.37%**	**-10.53%**	**-8.50%**

Table 4: Change in maintenance costs (S3).
Source: Created by the authors.

"Anipsis" spends 169.60 EUR on maintenance related activities. After implementing the M2M solution, the maintenance costs can be reduced by 15.89 EUR in the Realistic scenario, 17.86 EUR in the Optimistic scenario, and 14.41 EUR in the Pessimistic scenario. Such changes reduce the maintenance costs by 9.37 per cent per month in the Realistic scenario, by 10.53 per cent in the Optimistic scenario, and by 8.5 per cent in the Pessimistic scenario.

5.5.5. Productivity and efficiency

Productivity is obtained by dividing inputs against outputs. Only the inputs that have changes during the simulation are included. In this case, it is the maintenance costs and electricity costs. Output is the gain from one cubic metre of logs. Output from one cubic metre of logs and the maintenance costs are presented in the previous sections. The electricity costs are adjusted according to the improvements in minutes worked per day presented in the next section. Productivity results are presented in Table 5 in the next page.

Productivity	Unit	Scenario			
		Base	Realistic	Optimistic	Pessimistic
Productivity	per cent	30.37	31.36	31.49	31.16
Productivity increase (% of Base)	per cent	100.00	**+3.15%**	**+3.54%**	**+2.52%**

Table 5: Productivity.
Source: Created by the authors.

The productivity estimate from the Base scenario is 30.37 per cent. The M2M solution improves productivity in the Realistic scenario by 3.15 per cent, in the Optimistic scenario by 3.54 per cent, and in the Pessimistic scenario by 2.52 per cent. This indicates that the M2M solution could increase the overall productivity of the sawmill.

Minutes worked per day is obtained as a utilization estimate. Since the M2M solution decreases the downtime, the saw's utilization is increased. The results for minutes worked per day are presented in Table 6.

Minutes worked per day	Unit	Scenario			
		Base	Realistic	Optimistic	Pessimistic
Minutes worked per day	minutes	435.45	452.66	453.02	452.39
Efficiency improvement (% of Base)	per cent	100.00	**+3.80%**	**+3.88%**	**+3.74%**

Table 6: Minutes worked per day.
Source: Created by the authors.

The M2M solution improves the efficiency relative to the Base scenario on average by 3.8 per cent in the Realistic scenario, 3.88 per cent in Optimistic scenario, and 3.74 per cent in Pessimistic scenario.

5.6. Net Present Value

Initial investment corresponds to the total cost of the M2M solution. The initial total costs are 725.50 EUR. The investment period is linked to the warranty period of the laser device. Thus, the investment period is 3 years.

Net benefits are associated with tax shield and a monthly decrease in maintenance costs from each scenario with the M2M solution. The net benefits and the corresponding net present values are presented in Table 7. So for the Realistic scenario the benefits for every year are worth 190.74 EUR, for the Optimistic scenario they are 214.38 EUR, and 172.92 EUR for the Pessimistic scenario. Tax shield for the scenarios each year is 36.28 EUR.

Scenario	Realistic	Optimistic	Pessimistic
Monthly benefits	15.89 €	17.86 €	14.41 €
NPV	**-115.56€**	**-52.06€**	**-163.44€**

Table 7: Net present value.
Source: Created by the authors.

The net present value results for the M2M solution reveals that the proposed investment project is not profitable. In all the scenarios, the net present estimates are negative. The sensitivity analysis shows that the monthly benefit should be around 19.40 EUR. Only in that case the M2M solution would pay off. In conclusion, the existing M2M off-the-shelf solutions cannot solve maintenance problems in a profitable way.

6. Discussion of results

The authors discussed the results of the model and validated the model with the manager of “Anipsis”. The manager approved that the general model conceptually represents the production process in the sawmill. In addition, he confirmed that the values produced by the model do not deviate significantly from the real production results. However, he could not comment on how feasible it is to reap the potential benefits of M2M. The authors believe that the lack of comments about potential benefits can be explained by the fact that the manager is not fully aware how effective the current maintenance practices are in the sawmill.

The analysis shows that the sawmill does not have a sophisticated production process with complex machinery. But “Anipsis” has not been able to introduce a maintenance process that is up to date. Maintenance practices are inefficient and the maintenance schedule only tracks the appointed time for inspections without recording any data. Thus, the current situation in the sawmill is not different from the situation described by Food and Agriculture Organization of the United Nations (1990) in the late 1980s.

The findings suggest that M2M solutions, which support maintenance processes in sawmills, can decrease downtime and maintenance costs. In general, the analysis supports the view of Al-Najjar (2007) that maintenance should be treated as a profit centre in micro and small sawmills. Even small savings can significantly improve the bottom line in the industry. The figures obtained during the research do not meet Manyika et al. (2013) maintenance cost saving figures. The authors estimate that the decrease in operational costs might range from 0.78 to 0.98 per cent. Nevertheless, the analysis indicates that introducing M2M technologies in the production process leads to improvements in productivity. In addition, it also supports the claim of Li et al. (2008). The claim states that improvements in maintenance practices can lead to cost advantage in woodworking industry. The results are relevant to other micro and small sawmills because all of them have similar production process. Thus, their cost structures are also rather homogenous. In addition, approximately 90 to 95 per cent of micro and small sawmills use continuous band saws.

The abovementioned indicates that M2M has a potential to have a significant impact on the operations in sawmills. However, the overall economic value at the moment is negative. The authors conclude that the technology is not mature enough and cannot yet be used to solve the existing maintenance practice inefficiencies. The authors claim that small-scale maintenance decision support can be improved, however, the gains from automation are small-scale. The M2M market has to develop by becoming more standardized and less segmented. Then the costs of M2M solutions will reach a more competitive level and might approach the potential estimated by Jensen et al. (2011) and Wadhawa (2012).

Ferber (2013) urges managers to respond to technological advance and the latest M2M developments. However, the authors see that sawmill managers are not aware of the technology and that their entities are not data-driven. Moreover, it will take time for M2M solutions to reach a more competitive cost level. In general, this is a good opportunity for sawmill managers to explore the market of automation technologies and the potential benefits that they provide. In addition, sawmill managers should prepare their organizations and production processes for new technologies. Then they will be able to deliver more economic value to their shareholders in the foreseeable future.

7. Conclusions

The sawmill “Anipsis” is an example of a woodworking company with maintenance inefficiencies. Around 95 per cent of small and micro sawmills have a highly homogenous production process and share similar maintenance problems. Suboptimal maintenance decisions and insufficient data create maintenance costs that lead to a waste of resources. In addition, operational problems affect the log yield and thereby decrease the productivity and profitability of sawmills.

Such technology as machine to machine has the potential to ease the maintenance practice. Existing literature lacks solid analysis and evidence of the M2M technology’s costs and risks. Yet the results of this research suggest that M2M solutions, which support maintenance processes in sawmills, can decrease downtime and maintenance costs. In addition, M2M solutions can increase productivity of production process. Altogether, the M2M technology can improve the production process of Latvian sawmills, however, it has high introduction costs.

To sum up, this research concludes that the net economic value is negative for M2M solutions which support the decision-making process of machine maintenance in Latvian sawmills. Overall, the technology has not matured enough yet. It cannot solve the existing maintenance practice inefficiencies in a cost effective way.

This research proves that the proposed M2M solution is not worth implementing yet. Further research can focus on other aspects of the M2M technology. Such aspects as the value of data and device connectivity issues can be analysed. In addition, further research can expand the solution to a bundle of solutions or analyse its applicability in other industries. Also, other issues related to M2M technologies can be assessed. Important issues such as data security, analytical capabilities of organizations and optimal architecture of M2M systems can be explored to fully assess the potential of M2M technologies.

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Appendices

Appendix 1. Definitions

Term	Definition
Machine to machine (M2M)	A system of technologies that communicate by themselves with a help of wireless or wired connection. It has grown rapidly due to the decrease in costs of data transmission via cellular and other networks.
Machinery maintenance	Any process that is performed in order to maintain the machinery in its best condition. In micro and small sawmills, the continuous band saw is the main maintenance object. It includes such processes as blade sharpening and changing, cleaning up, and checking for any damage.
Machinery wear	Every part of machinery has its own lifespan because the parts are worn-out during production process. In sawmills, machinery wear is mainly associated with saw's wear as it has a particular period of time after which the teeth of blade can't be sharpened anymore.
Sawmill	A type of factory which operates by sawing logs into planks or boards using different machinery. There are hardwood and softwood sawmills. Hardwood sawmills operate with oak, ash, or beech (mainly broadleaved trees). Softwood sawmills operate with pine, fire or spruce (mainly conifer trees).
Log conversion costs	The costs that appear directly or indirectly during log conversion process. During that process logs are cut into planks or other products. It includes production costs, maintenance costs and any other costs that are linked to the log breakdown phase.
Downtime	Time when a particular type of machinery (saw) is stopped due to blade cleaning or changing or blade's alignment adjustments.
Production time	A time for one log to be fully converted into planks or any other product. Combines downtime and sawing time, includes also the time spent on impregnation and slack time in-between production processes.
Maintenance costs	Costs appearing from maintenance decisions. Includes lost production time and expenses for spare parts.
Off-the-shelf M2M solution	An M2M solution that is comprised only from standardized and purchasable products. Solution itself can be adjusted and other products can be added. This research treats an M2M solution as a bundle of products provided in Appendix 2.
Sawing time	The sawing time for one log to be fully converted into planks or any other product. Can be perceived as machinery up-time.
Class 1 production	The output that is sold as top quality product. It does not contain any visible damage, pressure marks. Can contain minor number of knots. In the sawmill "Anipsis", the length of these products is 4.8m or 6m.
Class 2 production	The output that is sold with minor visible defects. Defects can appear due to mistakes in production process or flaws in storage procedure (waviness, warping, split ends, different thickness, etc). In the sawmill "Anipsis", the length of these products is 3, 2, 1.5 or 1 metre.
Production process	An industrial process that involves mechanical and chemical steps to manufacture raw material or materials to obtain different end products. It involves costs of mechanical and chemical steps, raw materials and labour and usually the end product become marketable.

Table 8: Term definitions. Definitions correspond to the meanings of terms as used in this report.
Source: Created by the authors.

Appendix 2. Description of the M2M solution

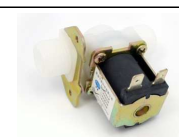
Descriptive	Sensor	Gateway	Fluid valve	Alarm
Company	Micro-epsilon	Micro-epsilon	SMC	Banner Engineering
M2M solution / Product	ILD-1302-200 Triangular laser distance sensor	IF2004/USB 4-channel RSB422-USB converter; IF2008 Interface card	Electronic solenoid valve	EZ-LIGHT™ 2-Color Indicators for Use with Sensors
Purpose	Measures distance till surface with triangular laser beam	Converts triangular laser pulse in USB signal, provides pulse path to PC.	Converts electric pulse in open valve setting	Alarm or environment indication
Advantages	Measuring ranges from 2 to 50 millimetres and supports rough surfaces. Mistake of 0.015 per cent, resolution up to 0.03µm. Adjustable measurement report rate of up to 49.02 kHz, software configuration and connectivity with other devices.	Can connect up to 4 channels of devices, autonomous memory option with synchronous data recording.	Opens when energized, small tube input and output (19 mm), stainless steel, fast acting response. Suitable for industrial manufacturing.	Thermoplastic polyester housing, thermoplastic diffuser, fully encapsulated. Operational conditions from -40°C to +50°C. Possible flashing mode. Suitable for industrial manufacturing.
Drawbacks	Vulnerable to direct dust layer on the device, quarterly calibration.	Interface card only for stationary computer.	Vulnerable to dirt creating jams or imperfect sealing	Vulnerable to physical damage.
Warranty	3 years	3 years	-	-
Maintenance costs per month	1.67 EUR (20 EUR per year)	-	0.17 EUR (2EUR per year)	-
Current price	400 EUR (laser sensor) 30 EUR (cable)	99 EUR (converter) 4 EUR (cable) 69 EUR (interface card)	7.50 EUR (valve) 30 EUR (cable)	30 EUR (indicator) 30 EUR (cable)
Device		 		

Table 9: Description of M2M solution. Micro-epsilon product specifications were retrieved from an interview with a sales representative and documents available on the official Micro-epsilon website. Details about prices and warranty were obtained from the respective companies.
Source: Created by the authors.

Appendix 3. Simulation model

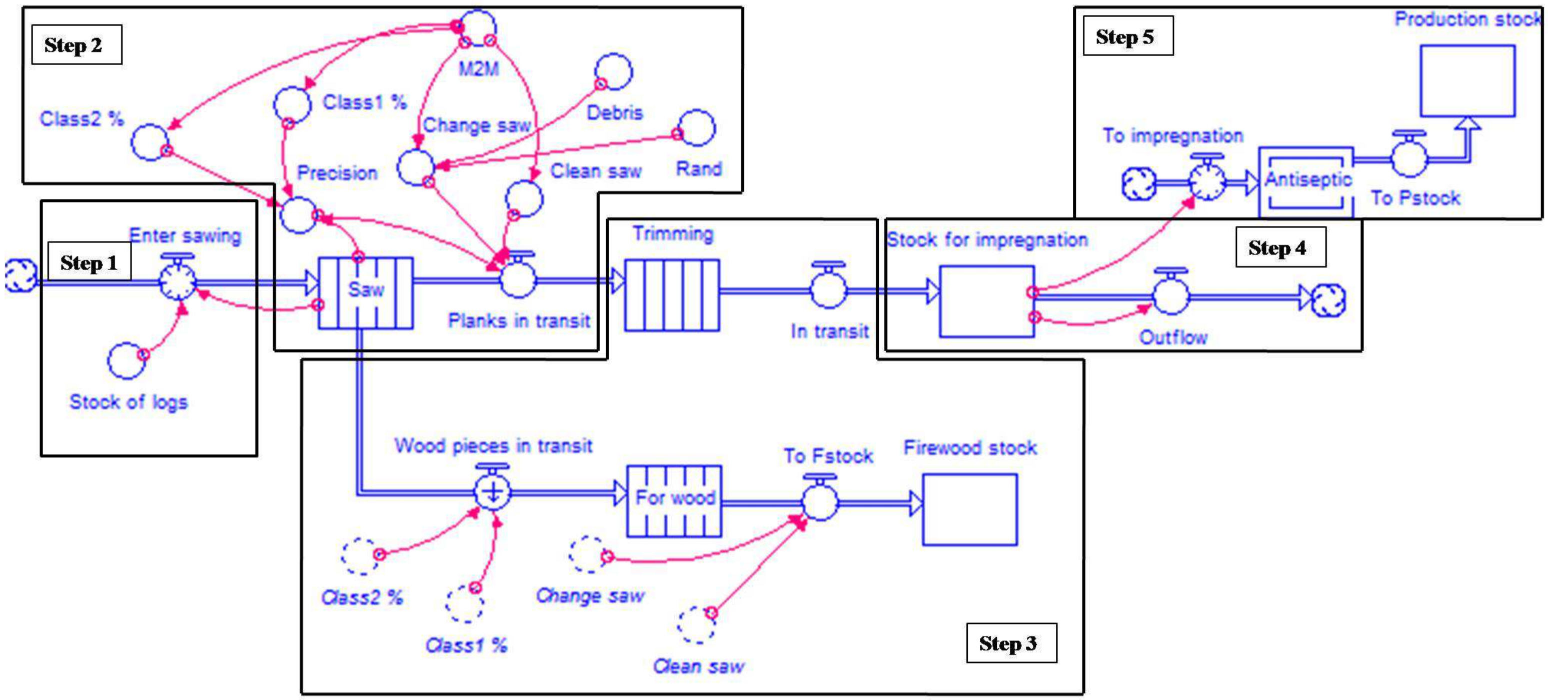


Figure 3: Simulation model. Step 1*:* An infinite number of logs are held in stock of raw materials. The logs enter sawing line one by one. The entry takes place only when the preceding log has been trimmed and stocked for impregnation. **Step 2***:* Factors like (a) sawing precision, (b) blade changing and (c) blade cleaning influence overall sawing time and quality of production. The quality is determined by a proportion between Class 1 and Class 2 products. Class 1 and Class 2 are expressed as a percentage of raw material volume. The proportion between Class 1 and Class 2 products depends on how precise is the sawing. In addition, the M2M solution developed by the authors can increase the sawing precision, thus, improving the quality of production. The saw can be damaged by debris during Step 2.Employees rarely can determine how substantial is the damage. However, M2M is the technology that can indicate whether the blade should be changed or it should not be changed in such case. Employees clean the blade according to the sawmill's time schedule and raw material qualities. The production process stops during the cleaning. However, the M2M solution can clean the blade automatically. Thus, the overall downtime decreases. The output of Step 2 is planks, they enter the next sawing phase, and wood pieces. The wood pieces enter the firewood production phase. **Step 3***:* The planks from Step 2 are re-sawed and trimmed, but wood pieces are converted in firewood. Processed by-products and firewood are stored in the firewood stock for sale. **Step 4***:* Re-sawed and trimmed planks are held in the stock that has to be impregnated. They move to Step 5 when the stock has reached 3 cubic meters of Class 1 and Class 2 production. **Step 5***:* Step 4 accumulates planks in the stock for antisepticising. The sawmill impregnates the planks with antiseptics. The last phase is to store impregnated planks in stock for sale.
Source: Created by the authors.

Appendix 4. Simulation code (the Base scenario)

BEGINNING OF THE CODE

```
Antiseptic(t) = Antiseptic(t - dt) + (To_antiseptic - To_Pstock) * dt
INIT Antiseptic = 0
    COOK TIME = varies
    CAPACITY = 9
    FILL TIME = 0.5

INFLOWS:
To_antiseptic = IF(Stock_for_antiseptic>= 9) THEN PULSE(9, 0.16) ELSE PULSE(0, 0.05)
OUTFLOWS:
To_Pstock = CONTENTS OF OVEN AFTER COOK TIME, ZERO OTHERWISE
    COOK TIME = NORMAL(3, 0.15)
Firewood_stock(t) = Firewood_stock(t - dt) + (To_Fstock) * dt
INIT Firewood_stock = To_Fstock*0.339763

INFLOWS:
To_Fstock = CONVEYOR OUTFLOW
    TRANSIT TIME = 2+Clean_saw+Change_saw
For_wood(t) = For_wood(t - dt) + (Wood_pieces_in_transit - To_Fstock) * dt
INIT For_wood = 0
    TRANSIT TIME = varies
    INFLOW LIMIT = INF
    CAPACITY = INF

INFLOWS:
Wood_pieces_in_transit = LEAKAGE OUTFLOW
    LEAKAGE FRACTION = (1-Class 1_%-Class2_%)
    NO-LEAK ZONE = 0%
OUTFLOWS:
To_Fstock = CONVEYOR OUTFLOW
    TRANSIT TIME = 2+Clean_saw+Change_saw
Production_stock(t) = Production_stock(t - dt) + (To_Pstock) * dt
INIT Production_stock = Antiseptic

INFLOWS:
To_Pstock = CONTENTS OF OVEN AFTER COOK TIME, ZERO OTHERWISE
    COOK TIME = NORMAL(3, 0.15)
Saw(t) = Saw(t - dt) + (Enter_sawing - Planks_in_transit - Wood_pieces_in_transit) * dt
INIT Saw = 0
    TRANSIT TIME = varies
    INFLOW LIMIT = INF
    CAPACITY = 1
INFLOWS:
Enter_sawing = PULSE(1,0.5,0.5)
OUTFLOWS:
Planks_in_transit = CONVEYOR OUTFLOW
    TRANSIT TIME = IF(Precision = 1) THEN (DT*4+Clean_saw+Change_saw)*1 ELSE DT*4+Clean_saw+Change_saw
Wood_pieces_in_transit = LEAKAGE OUTFLOW
    LEAKAGE FRACTION = (1-Class 1_%-Class2_%)
    NO-LEAK ZONE = 0%
Sawing_and_Impregnation(t) = Sawing_and_Impregnation(t - dt) + (Planks_in_transit - In_transit) * dt
INIT Sawing_and_Impregnation = 0
    TRANSIT TIME = 0.5
    INFLOW LIMIT = INF
    CAPACITY = INF

INFLOWS:
Planks_in_transit = CONVEYOR OUTFLOW
    TRANSIT TIME = IF(Precision = 1) THEN (DT*4+Clean_saw+Change_saw)*1 ELSE DT*4+Clean_saw+Change_saw
OUTFLOWS:
In_transit = CONVEYOR OUTFLOW
Stock_for_antiseptic(t) = Stock_for_antiseptic(t - dt) + (In_transit - Outflow) * dt
INIT Stock_for_antiseptic = 9

INFLOWS:
In_transit = CONVEYOR OUTFLOW
OUTFLOWS:
Outflow = IF(Stock_for_antiseptic>= 9) THEN PULSE(9,0.16) ELSE PULSE(0,0.05)
Change_saw = IF(Debris < 1) THEN PULSE(0.05, Rand,Rand) ELSE (IF(M2M=1) THEN PULSE(0.05, 2 + NORMAL(0.12,0.12),2 + NORMAL(0.12,0.12)) ELSE PULSE(0.05,2,2))
Class 1_% = IF(M2M = 1) THEN NORMAL(0.27,0.025) ELSE NORMAL(0.27,0.05)
Class2_% = IF(M2M = 1) THEN NORMAL(0.23,0.025) ELSE NORMAL(0.23, 0.05)
Clean_saw = IF(M2M=1) THEN 0 ELSE PULSE(0.025,0.5,0.5)
Debris = RANDOM(0,40)
M2M = 0
M3 = 0.339763*Production_stock
M3F = 0.339763*Firewood_stock
Precision = IF(Class 1_%-0.25>Class2_%) THEN 1 ELSE Saw*0
Rand = RANDOM(0,2)
Stock_of_logs = PULSE(1,0.05,0.05)
```

ENC OF THE CODE

Appendix 5. Simulation variables

Variable	Values				Unit	Description
	Base	Realistic	Optimistic	Pessimistic		
Time frame	176	176	176	176	hours	8 working hour per day. 22 working days per month.
Firewood	varies	varies	varies	varies	per cent	Depends on Class 1 and Class 2 production.
M2M solution	0	1	1	1		Dummy variable: M2M solution is used (1); otherwise (0).
Standard deviation of Class 1 production	5	2.5	1.5	3.5	per cent	On average Class 1 production is 47 per cent of initial volume of raw materials and it is normally distributed.
Standard deviation of Class 2 production	5	2.5	1.5	3.5	per cent	On average Class 2 production is 23 per cent of initial volume of raw materials and it is normally distributed.
Time for cleaning the blade	1	0	0	0	minutes	Every 30 minutes employee cleans the blade.
Time for changing the blade	6	6	6	6	minutes	Every 120 minutes employees change the blade. The timing also depends on the number of logs containing debris.
Timing for changing the blade	120	[120;134]	[120;139]	[120;129]	minutes	In base case, the blade is changed according to saw manufacturer's instructions. If M2M solution equals 1, then saw's usage time is extended.
Standard deviation of antisepticising process	15	15	15	15	minutes	On average the antisepticising process lasts for 180 minutes and is normally distributed.
Sawing precision	0 : 0	1 : 1.02	1 : 1.01	1 : 1.03	dummy : coefficient	Dummy variable: An increase in sawing precision (1) increases sawing time; otherwise (0). Sawing precision depends on the presence of M2M solution.

Table 10: Simulation variables. The table provides an overview of simulation's variables. Variables are adjusted according to the model's limitations and assumptions. Time frame for one simulation is 176 hours or one working month with 22 working days. Firewood is expressed as a leftover of the log after Class 1 and Class 2 material is processed. The M2M solution is either turned on or off. Logs differ in their output volume creating deviations in Class 1, Class 2 and firewood production. Different timing takes place for maintaining the saw. The timing depends on maintenance procedure or the presence of debris. The values of input variables are collected by the authors observations in the sawmill or provided by the manager or M2M technology sales persons.
Source: Created by the authors.

Appendix 6. Significance tests

Significance tests for simulation variables

Compared to Base		Output(m3)	Firewood (m3)	Class 1 %	Class 2 %	Firewood %
realistic	t value	40.469***	20.821***	0.690	1.110	0.468
optimistic	t value	40.248***	26.125***	0.526	1.476	0.242
pessimistic	t value	46.042***	26.195***	0.561	2.294*	0.053

Table 11:Variable significance tests comparing scenarios with M2M to Base.
Source: Created by the authors.

Between scenarios		Output(m3)	Firewood (m3)	Class 1 %	Class 2 %	Firewood %
realistic / optimistic	t value	2.394*	19.052***	1.560	0.550	1.451
realistic / pessimistic	t value	1.627	19.823***	0.864	1.833*	2.033*
optimistic / pessimistic	t value	0.818	0.049	0.284	1.558	1.052

Table 12:Variable significance tests between scenarios with M2M.
Source: Created by the authors.

Significance tests for maintenance time

Compared to Base		Downtime
realistic	t value	10.955***
optimistic	t value	37.477***
pessimistic	t value	50.640***

Table 13:Significance tests for downtime comparing scenarios with M2M to Base.
Source: Created by the authors.

Between scenarios		Downtime
realistic / optimistic	t value	26.610***
realistic / pessimistic	t value	39.870***
optimistic / pessimistic	t value	13.395***

Table 14: Significance tests for downtime between scenarios with M2M.
Source: Created by the authors.

Critical values

T values	Significance level				
one sided	5.00%	2.50%	1.00%	0.50%	0.05%
two sided	10.00%	5.00%	2.00%	1.00%	0.10%
Critical value	**1.676***	**2.009**	**2.403****	**2.678**	**3.496*****
Degrees of freedom	50				

Table 15:Critical values of significance tests.
Source: Created by the authors.