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Developing dynamic maintenance to achieve sustainable, robust and resilient production – a case study from a sawmill

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Abstract. The wood manufacturing industry is essential to the net-zero transition, offering renewable materials and biofuels that reduce reliance on fossil-based products. Within this value chain, the sawmill industry plays a key role but remains technologically inconsistent. While many operations are automated to Industry 3.0 standards, Industry 4.0 adoption is limited, and the prevailing mindset still reflects mass production rather than customer-driven approaches. This study aims to enhance sustainability and material efficiency by developing dynamic maintenance strategies that support robust, resilient, and waste-minimized production. Maintenance and reliability in sawmills are underexplored, and this research bridges a gap between industry and academia by leveraging Industry 4.0/5.0 capabilities.

A qualitative case study was conducted at a Swedish sawmill, involving 21 interviews and three workshops with maintenance and operations personnel, supported by a literature review. Findings highlight the importance of communication, collaboration, and clear roles for effective planning and sustainable maintenance. Leadership visibility and continuous competence development are key enablers of change. The study introduces the concept of dynamic maintenance, built on four pillars: shared goals, collaborative organization, value chain coordination, and appropriate technological support. These are enabled by a holistic perspective, organizational readiness for change, and data-driven decision-making. Achieving this requires strong leadership, participation, and a deep understanding of production processes. Competence development must address both organizational and technical aspects, including World-Class Maintenance and smart digitalization aligned with Industry 4.0/5.0.

Keywords: Industrial maintenance, Industry 4.0/5.0, Wood manufacturing, Sustainable production, Net Zero Industry

1. Introduction

The wood manufacturing industry plays an important role in the transformation towards net zero industry and helps in reducing greenhouse gases by, among other things, producing renewable materials and biofuels. When wood-based products replace fossil materials and fuels, a substitution effect occurs that contributes to reduced greenhouse gas emissions. The global production of sawn wood in 2020 was 473 million cubic meter, with Europe produced just over one third, while Asia and North & Central America produced over one quarter respectively.[1] Each year, approximately 19 million cubic meters of sawn wood are produced in Sweden, which equals the third largest exporter of sawn timber in 2020, after Russia and Canada.[2] The majority of Swedish wood companies are small and medium-sized enterprises located in rural areas. Skogsforum[3] reports that the number of sawmills has decreased by as much as 80% over a 50-year period, while total production has increased by 35%. This is a classic consolidation with fewer and larger units adopting a cost-driven production strategy. However, consolidation alone is not enough, the wood processing industry still struggles with profitability. Timber prices fluctuate due to a volatile global environment, while log prices remain historically high. The national demand for wood sawn products in Sweden during last year was the lowest since 1990s and the inventory levels are continuing low.[4] This unique combination of low demand of sawn goods with low forest inventory levels has decreased the revenue and increased the cost in the industry. Raw material shortages have limited production in Canada and much of Europe. The Canadian forestry group Canfor halted production at two sawmills in 2024. Not only is the sawmill sector under pressure, but subsequent processing stages are also significantly affected. In March 2025, the forestry group Setra issued layoff notices to 60 employees in Långshyttan and paused its production of cross-laminated timber due to lack of profitability.[5] Moelven decided in May this year to close down their sawmill in Ransby due to the same reason.[6] In the woodworking industry, 40 companies went bankrupt in 2024.[7] Reduced turnover also affects companies in the construction industry that use wood products.[8] Laws and regulations, such as the EU regulation on nature restoration, also have an impact on the wood industry. There are strong incentives to improve profitability and focus on further increasing resource and process efficiency. At the same time, the advantages of wood are many as a renewable resource that can reduce climate impact compared to traditional construction methods.[9]

The sawmill industry is characterized by complex value chains, making sustainability and resource efficiency essential at every stage and the current market situation has pushed the need to find new strategies to stay profitable. The sawmill industry, an important part of the wood value chain, relies on capital-intensive equipment that requires high reliability and productivity. Another aspect is that the different operations along the sawmill process varies largely in time, e.g., the drying process takes days, whereas the sawing quickly transforms logs to lumber.[10] A characteristic of the forest-to-lumber industry is the material flows according to the push principle, rather than the lean management pull principle. The industry's reluctance to embrace lean and agile principles stems from uncertain economic impacts during market fluctuations.[11] There are several characteristics of the sawmill production processes that add to the complexity of production planning and control.[12] One such characteristic is the heterogeneity of the raw material, i.e., logs vary in shapes and qualities.[13] Further, it is a contradictory industry in terms of technological development[14], i.e., any process steps have a high degree of automation equivalent to Industry (I3.0), but with a low level of adoption of Industry (I4.0) technology. At the same time, the prevailing mindset is still based on mass production, equivalent to Industry (I2.0), rather than customer order management. The focus remains on maximizing output, rather than optimizing the value of the raw material.

I4.0 is a term encompassing digital tools and concepts e.g. Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data (BD) analytics. Such approaches join the complete value chain from idea to recycling.[15] Understanding the roles of people and organizations in adopting new technologies has become crucial for successful digital transformation.[16,17] This perspective is explicitly emphasized by Industry 5.0 (I5.0), which focuses on creating a sustainable, resilient, and human-centred industry that effectively leverages technological solutions.[18] Maintenance and operational reliability are particularly well suited for technological intensification.[19] Emphasizing operational reliability and the uncertain aspects of maintenance work can reduce disruptions, stabilize processes, enhance resource efficiency, lower raw material use and energy consumption, and extend the lifespan of mechanical equipment.[20] I4.0 technologies and predictive analytics are key approaches to advancing how maintenance is planned, executed, and optimized. Such approaches can lower downtime and extend machine equipment life through predictive methods, real-time monitoring, and data-driven decision-making.[19,21,22]

Current machine equipment in sawmills can generate and collect a large amount of production data with the potential to transform the sector. Meaning that data that is gathered from log arrival into the woodyard and throughout the production until to the final products leaves could be used to advance the sawmill industry. Improved data utilization is important to maintain competitiveness and thus, the sawmill industry has large potential of moving forth with their digital transformation. Hence, it is of interest to investigate how maintenance operations can evolve toward a value-driven transformation aligned with the concepts of I4.0 and the principles of I5.0. The study emphasizes, in line with I5.0, how digital transformation can enhance human centricity, sustainability, and resilience. Furthermore, to support the substitution effect, the research focuses on developing maintenance strategies that promote sustainable, robust, and resilient production with minimal waste and operational disturbances, while optimizing material utilization. The aim of the study is to develop a concept to transform maintenance and operational reliability practices in the sawmill industry by leveraging the potential of I4.0 and I5.0. This transformation is complex and requires a radical shift in mindset and attitudes, as well as changes in working methods coupled with suitable use of technologies and data analytics. The transformation must ensure that production remains sustainable, robust and resilient. As a first step in the transition, it is essential to assess the current state of maintenance practices and technological maturity to identify appropriate solutions and effectively guide the development process.

2. Theoretical frameworks

The development from the industrial revolution to the present day can be described through different eras where technological development has enabled major development steps from an agricultural society and one-piece manufacturing via mechanization (Industry 1.0) and mass production (Industry 2.0) to automation (Industry 3.0) and digitalization (Industry 4.0). The focus has been on production – to produce more, faster, safer and more economically. However, to have safe, reliable and profitable production, machines and equipment must be maintained. Maintenance has followed the development of production and methods have been developed with a focus linked to the different industrial eras[23], from reactive and corrective maintenance (I1.0) to preventive (I2.0) to more predictive (I3.0) and prescriptive (I4.0).

As production has become more automated and digitalized, maintenance methods have developed with the capability to collect large amounts of data from production. Through data-driven maintenance, it is possible to predict and plan maintenance efforts in a completely new way. However, it is becoming increasingly clear that the human factor is essential for continued development and progression. Critical thinking through human interaction with machines and systems is important for creating sustainable, human-centred and resilient industry. Therefore, the knowledge, competence and skill of employees/people are essential and the focus of Industry 5.0. This progress, focusing on the human aspects and importance of learning[17], has been ongoing for the last twenty years. Some concepts have had elements of this development, for example total productive maintenance (TPM) where employees' involvement and commitment are essential for the maintenance-management system.[24] TPM focus continuous improvements on the equipment and the production, involving employees from both the production department and the maintenance department. [24] The purpose is to increase the overall equipment effectiveness by autonomous maintenance making safe and robust processes, based on the principle that equipment improvements must involve everyone in the organization. [24]

Since TPM has a holistic view of the production and maintenance departments, the concept could help maintenance become an integral part of strategy using maintenance as a competitive business strategy. Other concepts developed in the last decades, for example world-class manufacturing and world-class maintenance also focus on the entire organization integrating different methods and tools to achieve a competitive organization with among other things zero defects, zero breakdowns, zero waste and zero accidents.[25] To create this, all parts of the organization and all employees must focus on world-class performance and continuous improvements in all processes, from strategy and management through production and maintenance to competence supply, competence assurance, education and training.

Competitiveness motivates industry to embrace business improvement methods to continuously and rapidly improve. Increased demands for sustainability, flexibility, cost efficiency and just-in-time delivery require robust and resilient production with a high level of equipment performance. To further strengthen this, the development and implementation of new technologies is required. Adopting new technologies requires coordinated changes in people, processes, structures, and strategy.[17,26] To succeed, organizations must develop capabilities; defined in the context of Industry 4.0 as the ability to effectively integrate and apply digital technologies to support strategic goals and create new business opportunities. [27] Huber et al.[27] identify three primary capabilities: *Connect and Store* (e.g., system interoperability, real-time data collection), *Understand and Act* (e.g., data analytics), and *Predict and Self-Optimise* (e.g., autonomous systems). These are supported by capabilities in *Strategy*, *Technology*, and *Human Resources*, which enhance organizational readiness and effectiveness.

As industrial operations grow in complexity and scale, digital transformation has become a critical enabler for modern maintenance practices.[23] In capital-intensive sectors, where unplanned downtime can lead to significant financial consequences, maintenance is increasingly viewed not as a reactive function but as a proactive driver of resilience and performance. [28] Its influence spans the entire asset lifecycle, from initial design and engineering decisions to end-of-life management, through activities that preserve, restore, or enhance asset functionality. This is referred to as asset management. Asset management originated in maintenance and dependability engineering, initially focusing on physical assets, such as infrastructure, equipment, and facilities, managed across their lifecycle to enhance performance, reduce costs, and mitigate risks.[29] The concept has since evolved into a strategic, interdisciplinary practice encompassing engineering, economics, risk, and human behaviour, and now includes intangible assets such as human, organizational, financial, and informational resources. ISO 55000 defines asset management as "the coordinated activity of an organization to realize value from assets," implemented through integrated strategies and actions throughout the asset lifecycle.[30] There are further trends that reflect the increasing digitalization, including the use of AI and machine learning for forecasting and optimization[30], and the adoption of immersive technologies, real-time data integration, and hybrid asset representation.[31]

Smart Maintenance is an organizational concept for maintenance in digitalized manufacturing.[32] The concept is developed in collaboration between industry practitioners and researchers and applicable to all subsectors of the manufacturing industry. For example, Ferm and Larsson[33] studied its implementation specifically in a company in the wood industry. Smart Maintenance consists of four key dimensions: (1) data-driven decisions; (2) human capital resource; (3) internal integration; and (4) external integration. [32] Studies show that maintenance performance evolves with high and balanced levels of the four key dimensions.[19] The implementation of Smart Maintenance can be supported by a structured strategy development process as proposed by Lundgren et al.[34]

The sawmill industry is characterized by high capital intensity, with substantial investments in machinery and equipment that demand consistent operational reliability. The production process is highly interdependent; thus, a disruption in any single section can lead to a complete halt of operations[12] and the heterogeneity of the raw material makes production planning challenging.[10] In addition, sawmills are associated with dusty, heavy and noisy work environments where moving machine parts and the constant flow of raw materials pose safety risks to people.[35] Despite those aspects, today's maintenance work is mainly based on planned maintenance measures that are carried out during non-ergonomic and possibly risky working conditions.[12] The traditional work environment and culture require change to meet the high demands that modern, safer work environments impose. When it comes to adopting concepts and principles for I4.0 and I5.0, the sawmill industry is therefore in need of development in novel and advanced technologies.[12] This transformation entails profound changes in working methods and the use of technology, as well as considering perspectives and attitudes.[17,26] Importantly, comparable to observations in the steel and automotive sectors, the forest industry may currently lack sufficient innovative drive[14] for technological transitions. To enable radical advancements, it is thus essential to cultivate a culture that fosters innovation and embraces change.[17] World-Class Maintenance, Maintenance 4.0, and Smart Maintenance are models that can support such change. The latter emphasizes data-driven decision-making and system integration[19] and this thinking industry underscores the human roles in ensuring operational reliability across digitalization.[22] These developments disrupt the prevailing silo mentality and conventional views of maintenance, fostering more human-centred and data-driven approaches. Furthermore, predictive maintenance enables greater planning dynamics, while continuous business development is vital for achieving a successful transformation.[36]

3. Theoretical frameworks

The research methodology section outlines the case study design, data collection and analysis.

3.1 Case study design

The sawmill industry holds significant industrial importance and is characterized by diverse technical solutions. Sawmill equipment and assets are typically large and capital-intensive, often based on simple mechanical designs, whereas measurement and monitoring systems are typically technologically sophisticated. This study was initiated through collaboration and dialogue with industry representatives, where maintenance was identified as a key area for development. A subsequent systematic literature review, using the keywords 'maintenance' and 'sawmill' in the databases Web of Science and Scopus, confirmed that maintenance and operational reliability within the sawmill sector is an underexplored area. Only one relevant research article found addressing the implementation of Reliability-Centred Maintenance in a South African sawmill.[37]

A qualitative case study was conducted at a Swedish sawmill, given that case studies allow for in-depth exploration of phenomena within their real-life contexts and retain holistic perspective.[38] The aim was to investigate and map the existing sawmill process and maintenance practices to identify opportunities for improvement. The selected sawmill was chosen due to its ongoing focus on initiatives related to maintenance improvement in recent years. Data collection was drawn on multiple sources, including literature reviews, interviews, workshops, and observations. This mixed-methods approach enabled examination of both human factors e.g., behaviours and work practices, and technical aspects related to production, maintenance, and technological maturity.

3.2 Data collection and analysis

Initial informal observations were conducted to gain a general understanding of production processes and equipment use. While employee interaction was limited at this stage, the insights obtained informed the design and structure of the subsequent interview phase. To achieve a deeper understanding of how sawmill employees experience their work in relation to organizational structures, technological aspects, and potential improvement, in-depth semi-structured interviews were carried out.[39] Interviews were conducted either in person at the sawmill or online via Microsoft Teams. During a four-month period (Nov. 2024 – Feb. 2025) a total of 21 interviews were conducted by two researchers. All interview sessions were audio-recorded with informed consent from the interviewees. To gain a holistic perspective, the interviewees represented a range of roles and functions within maintenance and operations, including maintenance managers, maintenance planners, project managers, mechanics, and electricians. This selection comprised responsibilities from emergency repairs to long-term planning and development initiatives.

Following the completion of interviews, an initial thematic analysis was performed to identify recurring patterns and themes related to maintenance practices and improvement opportunities. Preliminary results were presented in two interactive workshops with sawmill employees. The first workshop included maintenance team leaders, while the second included production managers, senior managers, and specialists. The workshops served both to validate the findings and to gather participants' perspectives on short- and long-term development needs within maintenance operations. A third and final workshop, with the same participants as the second, focused on prioritizing and planning concrete initiatives that had been identified during the preceding interviews and workshops. The workshops included group discussions and collaborative exercises to support shared understanding and decision-making.

4. Results and Analysis

This section presents the results from the interview study and subsequent workshops. The findings are used to conceptualize the notion of dynamic maintenance. The empirical results are organized into the three themes 1) Holistic perspective, 2) Organizational change management, and 3) Data-driven decisions.

4.1 Holistic perspective

During the interviews, organizational and technical aspects emerged that both worked well and needed improvement. Those aspects were presented and further discussed during workshops to get a deeper understanding and a more holistic view. Results from these workshops indicated the need for a long-term overall maintenance strategy, better knowledge and understanding about maintenance in general and lifecycle and assets management, condition-based maintenance and autonomous maintenance. In addition, it became clear that operational knowledge needed to be developed so that employees could take on increased responsibility. A prerequisite for this is to clarify roles and responsibilities and to plan internal training. Summarizing the workshops, it became clear that there was a great need to clarify the importance of leadership and its role in creating a vision and strategy for maintenance. The strategy needs to be both short- and long-term, striving for shared goals, and clearly reveals the need for collaboration and communication between production staff and the maintenance department.

For employees to take on increased responsibility, there must be a shift in the overall culture and attitudes towards maintenance as costly and disruptive to production. There is a need for information, cooperation and communication among all departments, starting with top management. Leaders through the organization must guide and support towards increased and clear responsibility for production and maintenance. All employees should take joint responsibility for the development of the organization by understanding their role in the organization and developing working methods together. This requires holistic perspective, knowledge, governance, trust, authority and mandate.

4.2 Organizational change management

Internally, collaboration is structured through daily meetings involving the maintenance manager, production leaders, and operators, as well as through daily pulse meetings and improvement initiatives that engage multiple departments. Externally, maintenance teams coordinate with suppliers, contractors, and consultants for specialist tasks, installations, and long-term development. Roles such as the maintenance development manager, project manager, and team leaders are key in facilitating both internal and external collaboration.

The findings indicate that collaboration within shift teams and between maintenance functions generally works well. Daily pulse meetings, shift handovers, and regular coordination between roles such as maintenance engineers, mechanics, electricians, and team leaders are considered valuable for exchanging information and being updated on recent events. Team leaders and planners serve as central hubs for internal communication, helping to ensure information flows both between teams and across organizational levels. However, information transfer between shifts remains a recurring issue, particularly over weekends. Contributing factors include a lack of structured handover routines and system support, as well as shift schedules that involve long breaks (e.g., a full week off after a weekend shift), which disrupt continuity. Cultural and attitudinal barriers also play a role; some individuals or teams adopt a “pass-it-on” mentality, leaving unresolved issues for the next shift, which undermines accountability and creates friction. Collaboration between maintenance and other functions, such as production, planning, and safety, is seen as essential but sometimes challenging due to differing expectations and perspectives. Communication gaps are also noted during organizational changes and projects, where decisions are sometimes perceived as poorly anchored. These findings highlight the need for clearer roles, responsibilities, and more visible leadership.

Utilization and coordination with external actors are vital for maintenance. There is no possibility for the maintenance technicians to have comprehensive and deep knowledge of all equipment and systems. Therefore, there is close cooperation between, for example, machine and system suppliers, which is coordinated by maintenance manager and maintenance engineers. External specialists also participate in projects and installations, support with the removal and removal of equipment, commissioning, troubleshooting and test runs. They are also hired for education and training in their specific equipment and/or systems. This is often coordinated by maintenance manager or project manager. There is also close cooperation with hired mechanics and electricians daily coordinated by team leaders for mechanics and electricity. The team leaders also coordinate with welding and mechanical engineering companies during major stops and repairs. During larger planned stops, external companies are also used for specialist maintenance and cleaning and decontamination in external environments.

To develop and improve maintenance in the long term, the organization collaborates with consultants and researchers. Often this is coordinated by maintenance development manager or innovation specialists. Since collaboration and cooperation both internally and externally are necessary for developing and changing the organization, it must be planned both short-term and long-term. This requires shared and communicated goals, clear communication, employee involvement, and consistent support accordingly a comprehensive maintenance strategy is required. Prerequisites for establishing organizational change management are committed and involved leadership, coordination throughout the entire value chain (including external parties) and collaborative organization.

4.3 Data-driven decisions

Interviews indicate that the primary computer system for collecting and analysing maintenance data is a newly implemented Computerized Maintenance Management System (CMMS), which has recently replaced previous maintenance management software. The new CMMS functions effectively for basic maintenance planning but currently lacks key capabilities, including automated report generation, periodic activity planning, and machine monitoring. Spare parts management is also identified as an area requiring improvement within the new CMMS implementation. In addition to the CMMS, several factory personnel regularly use an event monitoring system, often referred to as an Overall Equipment Effectiveness (OEE) system), which provides a comprehensive overview of disturbances from both production and maintenance perspectives. However, within the event monitoring system, operator and technician data labelling has been reported as problematic, resulting in data quality issues. Standard office software, such as Microsoft Teams, is frequently used by factory staff for information sharing. Despite the adoption of various technological tools for maintenance planning and execution, interview responses suggest that current technologies are not being fully utilized. Several interviewees noted that while numerous new technologies have been implemented, generating significant amounts of data and information, they have not yet been scaled or integrated into routine practice. One such recently introduced technology is vibration analysis, which has been installed and is currently getting integrated into existing work procedures.

There is a clear aspiration to advance toward fact-based decision-making in maintenance planning and management. This is a critical area for improvement within the company, and some relevant investments have already been initiated. Existing solutions primarily offer descriptive decision support and data visualization, for example through dashboards. According to interviewees, the current technological capabilities adequately support the execution of present work roles; however, there is a strong interest in transitioning from descriptive analysis toward predictive maintenance, as well as in exploring the potential of artificial intelligence (AI) to enhance data-driven decision-making in the future. Competence development and training are considered essential for both leveraging existing technologies and enabling the development of future functionalities. While education and training programs are necessary, employees also require sufficient time and organizational commitment to engage meaningfully with the training. Effective competence development can improve proficiency in technological tools and foster greater trust in emerging technologies.

5. The concept of dynamic maintenance

Findings from the interview study indicate that organizational aspects such as communication and collaboration are crucial to ensure efficient production and maintenance planning, as well as for aligning priorities. Moreover, there is often a need to clarify roles and responsibilities, and a more visible leadership to support a culture of continuous improvement and change. The results also point to the need for shared goals to avoid sub-optimization at the functional level. Development initiatives must be anchored in the organization to ensure relevance and long-term impact. Furthermore, the study shows that there is a need for skills development that includes both introductory training, on-the-job training, and deeper theoretical and technical skills development. In addition, the study emphasizes the importance of data-driven decision making. Organizations need to systematically collect, analyse, and act on operational and strategic data to support continuous improvement, enable predictive maintenance, and align decisions across functions. While existing models like total productive maintenance and world-class maintenance highlight the importance of these factors, they are not sufficient to fully support the transformation required in an Industry 5.0 context.

Based on these insights, the concept of dynamic maintenance is proposed, see Figure 1. The term dynamic maintenance reflects the increasing need for adaptability and responsiveness in maintenance practices. In today's complex and rapidly evolving production environments, static and standardized approaches are no longer sufficient. Maintenance must continuously evolve in response to shifting production priorities, emerging technologies, and organizational change. The concept of dynamic maintenance captures this transformation by emphasizing organisational flexibility, real-time coordination, and digital readiness. The four pillars of dynamic maintenance, derived from[17,22,29,32,34], are 1) shared goals, 2) collaborative organization, 3) value chain coordination, and 4) supporting technology. Together, they offer a framework for navigating complexity and fostering continuous improvement in modern production environments. The shift encompasses technology use, work processes, culture, and organizational changes – areas that must be studied in an integrated way to achieve system-related synergy effects, which is the approach of dynamic maintenance.

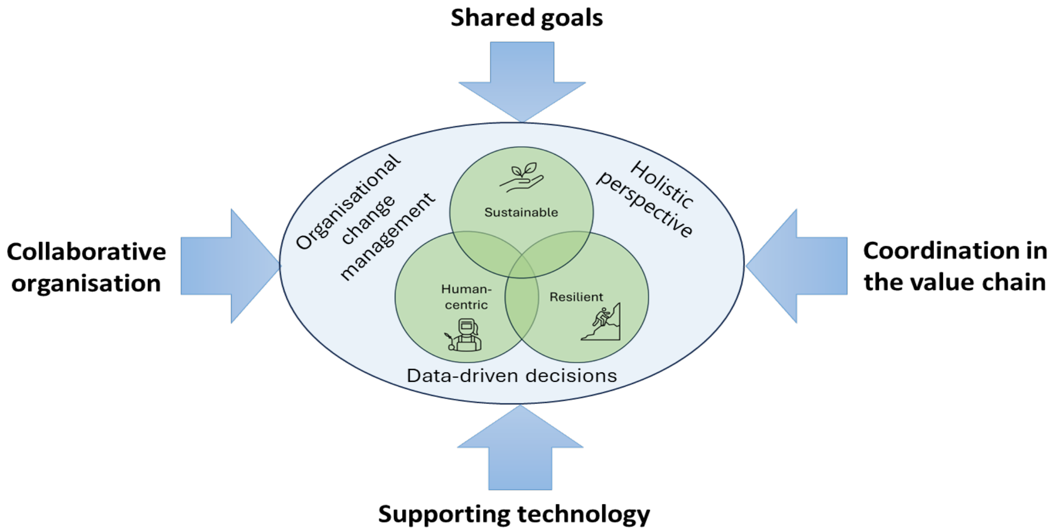

Figure 1. The concept of dynamic maintenance.

The four pillars are not standalone elements. Instead, they are highly interconnected and enabled by key organizational capabilities, organizational change management, a holistic perspective, and data-driven decision-making. Organisational change management facilitates the required shift and provides structural and cultural foundations for the implementation of the pillars.[17,24] This includes aspects such as leadership engagement, role clarity, and employee involvement, change management, and fostering collaboration across departments and functions. This also fosters mutual understanding and respect, leading to an improved work environment.[17,24] Applying a holistic perspective ensures that maintenance is viewed as a value generating and integral part of the production system.[29] This requires coordination and collaboration between internal and external actors to achieve effective asset management.[15,30] It also supports the alignment of maintenance strategies with broader organizational objectives, including sustainability and resilience.[17, 29] Data-driven decision making facilitates the organization's ability to understand and act on events and plan relevant actions.[27] It enables predictive and prescriptive maintenance through real-time monitoring, performance tracking, and informed planning.[21] This capability enhances transparency, supports continuous improvement, and strengthens the technological pillar by ensuring that digital tools are effectively utilized to support strategic goals.[19] Together, these enabling capabilities ensure that the four pillars of dynamic maintenance contribute meaningfully to the overarching goals of sustainability, human-centricity, and resilience. They create the conditions for a maintenance strategy that is adaptive, inclusive, and aligned with the demands of modern industrial environments.

Maintenance dynamics refers to the continuous adaptation of maintenance activities, strategies, and organizational capabilities in response to increasing complexity, evolving production conditions, and technological change. Based on empirical findings from the sawmill case study and existing literature, we identify three key types: maintenance planning dynamics, dynamic processes and interactions, and dynamic digital capabilities. *Maintenance planning dynamics* involve flexibility in both time and scope. Instead of following fixed schedules, maintenance can be advanced or postponed based on equipment condition[40], and tasks can be adjusted during planned stops.[41] Empirical data from the case study show that planning often shifts in response to production priorities, with interviewees describing both early interventions to prevent breakdowns and postponed actions to avoid disruptions. *Dynamic processes and interactions* reflect the need for real-time coordination within and across organizational boundaries. Communication between shifts, departments, and external actors is essential, and maintenance becomes a collaborative effort shaped by operational demands. This aligns with concepts such as TPM, Maintenance 4.0/5.0, asset management, and Smart Maintenance.[19,22,24] *Dynamic digital capabilities* refer to the organization's ability to sense and respond to change through digital technologies.[27,42] In maintenance, this includes adopting new tools, developing human capital, and coordinating across the value chain. The case study highlights the importance of leadership, learning, and readiness for change as key enablers of resilience and sustainability in line with Industry 5.0 principles.[17,18]

In summary, dynamic maintenance provides an adaptive framework for managing maintenance in complex industrial settings. By integrating organizational flexibility, collaboration, and digital capabilities, it supports both operational efficiency and long-term sustainability in line with Industry 5.0 demands.

6. Conclusion

This study fills an important gap between both industrial and research perspectives, as maintenance and operational reliability in the sawmill industry have not previously been the focus of innovative efforts and remain relatively unexplored. The main result is the conceptualisation of dynamic maintenance, showing the essentials for creating a robust and resource-efficient sawmill industry with a socially sustainable work environment. To achieve this there must be strong focus on organizational aspects and leadership to create commitment and understanding of the production process through participation and skills development. Such focus facilitates improved work environments. The need for competence development, i.e., up-skilling and re-skilling, encompass both organizational and technical areas such as concept of World-Class Maintenance, digital capabilities for Industry 4.0/5.0, new systems for data analytics and AI-related tools. Digitalisation plays a central role in enabling dynamic maintenance by providing the tools and infrastructure needed for real-time monitoring, predictive analytics, and cross-functional coordination. It supports data-driven decision making and helps organizations respond proactively to changes in production conditions, equipment status, and operational priorities. Developing dynamic maintenance strategies is essential for achieving sustainable, robust, and resilient production. Leveraging I4.0 technologies and I5.0 perspectives can transform maintenance and operational reliability in the sawmill industry by enabling data-driven, adaptive, and human-centric practices. This shift supports the net-zero transition a more sustainable and resilient production ecosystems for future industry.

As an extension of this study and the concept of dynamic maintenance described herein further research is proposed to focus on the managerial dimensions of resource-efficient and human-centric maintenance. Future research directions may also explore the application of technologies for anomaly detection and predictive maintenance through the analysis of process parameters, event data, and visual information (e.g., video recordings). The implementation of dynamic maintenance in the sawmill industry is anticipated to be challenging, primarily due to the sector's generally low level of digital maturity and its reliance on experience-based practices within maintenance organizations. Nonetheless, collaborative efforts between industry and academia have the potential to address these challenges, facilitating the adoption of technology in human-centric maintenance practices and contributing to more sustainable and resilient production flows in the sawmill industry.

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