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Enhancing Performance in Engineering-To-Order Projects: Integrating Digital Value Stream Mapping and Green Lean Practices

Daria Larsson, R.M. Chandima Ratnayake, and Samindi M.K Samarakoon

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ABSTRACT

The implementation of digital Value Stream Mapping (VSM) can enhance the efficiency of business processes (BPs) in engineering knowledge work by identifying and eliminating waste, with a positive impact on sustainability. The study utilizes a combination of action research and case study methodology. It begins with an extensive literature review, followed by a case study conducted within an engineering-to-order (ETO) electrical company, where insights are gathered through interviews. The techniques used include a literature review on VSM applications across different industries, a case study implementation of VSM in an ETO company, and interviews with 10 employees to identify process inefficiencies and improvement opportunities. The study reveals that digital VSM effectively identifies waste and non-value-adding (NVA) activities in engineering knowledge work, offering actionable insights for improving process efficiency and sustainability. This contributes to both academic understanding and practical applications in industrial settings.

KEYWORDS

Digital Value Stream Mapping; sustainability; knowledge work; Business Process Management; engineering-to-order; project performance

EMJ FOCUS AREAS

Sustainability; Organizational & Performance Assessment; Organization Development & Change; Continuous Improvement

Introduction

In contemporary society, knowledge workers play a vital role in driving innovation and progress across various industries. These individuals, encompassing diverse professions such as designers, researchers, lawyers, physicians, pharmacists, and financial analysts, possess formal higher education and analytical expertise to face complex challenges (Drucker, 1959). Their specific skills and creativity are pivotal in fostering innovation within engineering companies (Drucker, 1969, 1999). Consequently, many engineering organizations prioritize effectively managing knowledge work and nurturing the potential of their knowledge workers to drive strategic growth (Davenport et al., 1996). While the importance of enhancing knowledge work productivity has been recognized by scholars such as Drucker (1969) and Holtshouse (2010), methodologies and frameworks for achieving this goal are still emerging, representing a gap in both academia and industrial applications.

Some researchers (Chen & Cox, 2012; Riezebos & Huisman, 2021; Stadnicka & Chandima Ratnayake, 2015) have documented the application of value stream mapping (VSM) in knowledge work-related areas for mapping and analyzing various knowledge work-related processes, identifying waste, and defining improvement opportunities. Moreover, VSM can be described as a standardized way of documenting (i.e., mapping) processes to illustrate the relationship between material flow and information flow (Braglia et al., 2006; Chen & Cox, 2012) and present value-adding (VA) and wasteful activities (Lacerda et al., 2016; Silva, 2012). In addition, VSM assists in reducing or eliminating non-value-adding (NVA) activities and focuses on targeted areas for process improvement (Andreadis et al., 2017; Belekoukias et al., 2014; Ciarapica et al., 2016; Damelio, 1996; Kuipera et al., 2016; Rother & Shook, 1998; Silva, 2012; Stadnicka & Chandima Ratnayake, 2017; Tapping & Shuker, 2003). According to Wan and Chen (2007), VSM is one of the most effective lean tools that also benefits organizations reliant on knowledge-based work (Biskupska & Ratnayake, 2019). Hence, investigating how to use VSM in engineering knowledge work and its relevance to operation managers is vital. Furthermore, VSM has been performed for administration, product development, or service sectors, and in the following industries: the electrical industry (Chen & Cox, 2012; Larsson et al., 2021), aircraft/aerospace industry (Stadnicka & Chandima Ratnayake, 2015), construction industry (Arbulu et al., 2003; Torres et al., 2018), gas valve industry (Dadashnejad & Valmohammadi, 2019), healthcare (Chadha et al., 2012; Claire et al., 2013; Dogan & Unutulmaz, 2014; Fashtali et al., 2016; Marin-Garcia et al., 2021; Vidal-Carreras Pilar et al., 2015), education (Riezebos & Huisman, 2021), and hospitality industry (Schroeder, 2017). In most of the presented case studies, VSM has been a successful tool for the enhancement of knowledge work-related processes; however, its potential for the enhancement of business processes (BPs) within knowledge work in engineering companies has not thoroughly been investigated.

The current literature lacks sufficient exploration of VSM application in engineering knowledge work and office activities, highlighting a significant knowledge gap. Addressing this

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need, this paper conducts a detailed analysis of digital VSM implementation, drawing insights from real-world case studies. The primary aim is to assess the practical application of digital VSM in engineering knowledge work, while also evaluating its sustainability impact. Inspired by established methodologies (Chen & Cox, 2012; Shou et al., 2017; Stadnicka & Chandima Ratnayake, 2015; Torres et al., 2018), the study seeks to develop a structured method for implementing digital VSM in knowledge work environments.

This study primarily aims to explore the implementation and practical value of digital VSM in engineering knowledge work, specifically investigating its potential to enhance BPs optimization through waste identification and reduction, with a particular focus on sustainability impacts. This study is driven by the following research questions:

(1) What methodologies and strategies can facilitate the effective implementation of digital VSM in the context of engineering knowledge work to enhance process efficiency?
(2) What are the anticipated impacts of digital VSM on sustainability within BPs in engineering environments?
(3) How does digital VSM aid in identifying and eliminating NVA activities within engineering knowledge work?
(4) Based on a case study performed in an engineering-to-order (ETO) electrical company, what actionable insights can be derived regarding the applicability of digital VSM, and how do these findings contribute to advancing both academic understanding and industrial practices?

The research methodology includes action research and case study-based approach, including a thorough literature review centered on BPs in knowledge work and various VSM approaches across different industrial sectors. A case study was performed in an ETO electrical company to assess the practical application of VSM in BPs. Interviews were conducted with 10 employees using a standardized format to gather insights, revealing opportunities for improving process efficiency by eliminating waste in engineering knowledge work. This study contributes valuable insights to academia and industry, enhancing understanding of how VSM can optimize BPs in specialized domains.

Background and Industrial Challenge

Characteristics of Knowledge Workers and Knowledge Work

Knowledge workers in engineering organizations

Knowledge workers in organizations carry out thousands of tasks in their daily business conduct (Conger, 2010). Engineering companies employ different types of knowledge workers whose knowledge, education, and experience are closely related to their positions. Common examples of knowledge work positions are, e.g. CAD operators, project managers, engineering managers, quality assurance managers, surveyors, and mechanical and electrical engineers.

Knowledge workers are organized into three main levels within the organizational structure: strategic, operational, and performance (Maccoby, 1996). These levels determine how knowledge is aggregated, targeted, and utilized within the organization. Strategic level managers set organizational goals, while operational managers implement strategies, and "doers" such as project managers, engineers, and technical assistants carry out tasks. Knowledge workers can be classified into various groups (Autor et al., 2003; Brinkley et al., 2009; Davenport, 2010; Elias & Purcell, 2004), including expert workers, transaction workers, integration workers, and collaboration workers (Davenport, 2010). Expert workers possess high autonomy and engage in creative tasks, while transaction workers perform routine tasks based on formal rules and procedures (Autor et al., 2003; Brinkley et al., 2009). Integration workers are involved in systematic and repeatable work, and collaboration workers rely on collaborative teams for improvisational tasks. Additional groups identified in engineering organizations include complex communication and routine cognitive workers, who interact with others to acquire and process information or perform mental tasks based on guidelines and procedures (Autor et al., 2003; Brinkley et al., 2009). Knowledge workers can also be categorized based on their educational background, including traditional graduate occupants, modern graduate occupants, and niche graduate occupants (Elias & Purcell, 2004).

Knowledge work within engineering organizations

Knowledge work in organizations has many forms: knowledge creation, distribution, sharing, application, use and reuse, knowledge capturing, preservation, and identification. Knowledge workers are often committed to their work; they are motivated by the will to perform their tasks well (Robert Austin: an Interview, 2002). Knowledge work can be more iterative than physical work and more oriented toward exploring, experiencing, and trying again (Robert Austin: an Interview, 2002). Thus, a knowledge-related task usually takes a lot of time. As knowledge work is intellectual, observing the results of individual employee actions is difficult. One of the challenges faced by engineering managers is that they cannot directly observe efforts in knowledge work; sometimes, the manager cannot even understand what the worker is doing and is not qualified to judge the results (Robert Austin: an Interview, 2002). In addition, performance measures often do not accurately reflect the outcomes of the performed task (Robert Austin: an Interview, 2002). Therefore, knowledge work-dependent organizations often fail to improve performance based on economic and physical key performance indicators (KPIs) such as revenue or the project margin (Larsson et al. 2021).

Business Process Management (BPM) Within Knowledge Work

In the modern business world, organizations that want to achieve a high level of efficiency are required to streamline their operations and integrate BPs (Sidorova & Isik, 2010). A BP can be defined as an activity or group of activities that form a workflow structure (Thompson, 1967) with logically related tasks (Davenport, 1993). A BP takes an input, processes that input to increase its value, and provides an output (Harrington, 1991) with the assumption that the inputs and outputs can be clearly identified (Davenport, 1993). The activities within the BP are interdependent, and tasks are organized in a way to achieve specific business goals (Raghu & Vinze, 2007).

BPM in knowledge work is an approach for designing, executing, analyzing, and dynamically adjusting BPs (Chen et al. 2009; Sidorova & Isik, 2010). Managing BPs for knowledge work can be challenging owing to, e.g., the complexity of the knowledge work processes, challenges related to observing and tracking knowledge, or the difficulty to define the quality or duration of the knowledge task.

The challenge to observe and track knowledge

According to Davenport (2010), knowledge work is invisible; therefore, it is difficult to track the flow of information (Chen & Cox, 2012) and material, and illustrate it in the process. In a physical work environment, material flow is visible and can be observed and mapped. However, in an office setting, information and material flow are often not visible, such as in the digital transfer of documents and e-mails. In addition, in the office environment, the definition and identification of waste is challenging (Chen & Cox, 2012). Typical waste identified in manufacturing environments (e.g., inventory, waiting, defects, transportation, over-processing, or excessive motion (Ohno, 1988)) is not easy to observe in the office environment. This is due to office tasks being assigned through e-mails or meetings, and the waste has often no physical form. Understanding the flow, rationale, and variations of the work process, while simultaneously analyzing and illustrating waste in knowledge work, requires considerable time.

The complexity of knowledge work processes

The engineering design process is complex and involves many steps because the design solution must satisfy the customer. An observation-based example is a team of engineers designing a multidisciplinary prototype based on customer specifications with different CAD programs. The engineers and designers communicate with each other daily, thereby exchanging ideas and discussing the design frequently. There are many interactions during this particular design process; therefore, creating a process map of all steps during the design process can be complex.

In addition, in engineering processes, tasks are not performed in a successive manner when one task is waiting for the previous one to finish; they are handled simultaneously and interlinked. In addition to the tasks, the documents and IT systems are interlinked. The number of tasks assigned to an employee is not always apparent, as some employees are capable of multitasking (Wan & Chen, 2007); this only adds complexity to the process map. Moreover, communication among engineers and among project managers, suppliers, and clients is complex (Kreimeyer & Lindemann, 2011).

The difficulty to define the quality and duration of a task

Estimating the exact time required to complete a task is challenging, as some tasks depend on confirmation from a manager or customer (Chen & Cox, 2012) and waiting for the decision can delay task execution. Additionally, determining whether a task has been completed successfully is challenging due to the numerous variables involved (Chen & Cox, 2012). An unambiguous assessment of the task is difficult, e.g. when the quality of the expected result has not been determined accurately in advance by the person giving the task. The biggest challenge in evaluating knowledge work lies in measuring the quality (Davenport, 2010); therefore, many organizations tend to fail by approaching knowledge from the perspective of the produced volume, e.g., the amount of engineering documentation created during the hours spent on the work.

VSM supporting BPM in order to improve knowledge work

Davenport (2010) advocates for a process-oriented approach to knowledge work, aligning with Kaplan and Norton (2001) view that process improvement centers on delivering value to the customer. BPM aims to enhance organizational processes to meet customer needs and strategic goals (Conger, 2010; Hammer, 2010). While BPM focuses on process design and implementation, researchers have increasingly emphasized ongoing management and control of BPs (Sidorova & Isik, 2010). However, BPM lacks methods for waste removal and improving ineffective process steps (Conger, 2010), necessitating support from complementary tools like Six Sigma. In the realm of knowledge work, process improvement tools are still evolving. VSM stands out as a tool capable of assessing and improving process performance by visualizing the current state, identifying waste, and envisioning future improvements (Abuthakeer et al., 2010; Ballard & Howell, 1994; Jasti & Sharma, 2014; Rother & Shook, 1998; Tabanli & Ertay, 2013). Additionally, VSM facilitates the identification of process constraints and waste (Grewal, 2008; Jeong & Yoon, 2016), enhancing process efficiency when combined with tools like check sheets, Pareto analysis, and root cause analysis (Conger, 2010).

How knowledge workers can contribute to improving the project performance

Typically, processes are designed, modeled, and developed by teams of analysts who are not directly involved in the actual project work and often have limited insight into how tasks are executed. According to the literature review, organizations will benefit more from improved BPs if they try to understand better the role of intellectual capital within BPs (Harrison-Broninski, 2010; Herremans & Isaac, 2004). Organizations must understand how individual workers accomplish their assigned tasks (Davenport, 2010) and define the '*practise side*' of knowledge work, which is the practical knowledge about the performed task (Brown & Duguid, 1991). This is specifically relevant when it comes to the process design.

Davenport (2010) suggests that to create a realistic process for knowledge work, it is recommended to involve knowledge workers in the process design. The more 'doers' (i.e. the lowest level in the organizational structure according to Maccoby (1996)) gain knowledge and responsibility, the more the value increases when they actively participate in planning work schedules as they know and understand the systems and processes. By adding '*practise*' to the process design, it is possible to visualize how the work is performed. Additionally, involving knowledge workers in process design enhances organizational culture, as they are more likely to support and adopt process changes when they have participated in the design (Davenport, 2010).

Owing to their practical experience and knowledge of interactions in the work process, knowledge workers can also make major contributions to process innovations (Scheib, 2003). Yesil et al. (2013) suggest that knowledge created, transferred, and shared within organizations is a primary driver of innovation, enabling companies to develop innovative products and services.

VSM Approaches to Knowledge Work

Office value stream

VSM is a standardized method of documenting process stages and analyzing them (Ali et al., 2015; Chen & Cox, 2012; Damelio, 1996; Rachman & Ratnayake, 2018; Ratnayake & Chaudry, 2017; Tapping & Shuker, 2003) in order to identify and eliminate waste (Jeong & Yoon, 2016). The outcome of VSM is a developed process improvement plan and added value for products and services (Chen & Cox, 2012). VSM was initially developed to support and enhance processes in manufacturing environments (Chen & Cox, 2012); therefore, most studies related to VSM concentrate on the manufacturing industry (Rother & Shook 1998; Shou et al., 2017; Yang et al., 2011) where VSM has helped reduce cycle times, minimize waste in the supply chain, boost productivity, and shorten lead times (Shou et al., 2017). VSM was later expanded for use in various organizations and office-based functions, including engineering design, customer service, and administration (Chen & Cox, 2012; Torres et al., 2018). As described in case studies (Chen & Cox, 2012; Torres et al., 2018), VSM performed in office environments requires a different approach than VSM applied in manufacturing. However, the presentation of knowledge work in terms of the process is challenging as knowledge work involves a lot of thinking, collaboration (Davenport, 2010), and autonomy; this can be incompatible with process forms, which are structured and sequenced.

In manufacturing, the value stream (VS) encompasses the steps involved in producing a physical product, from raw material acquisition to final assembly. Conversely, in office environments, the VS begins with knowledge transfer through verbal communication, documents, or e-mails (Keyte & Locher, 2015). From the project's start to the delivery of product, the knowledge work VS includes activities like as sales, customer service, and engineering (Keyte & Locher, 2015; Martin & associates, 2021) (Exhibit 1).

Use of VSM approaches to knowledge work in different industries

Exhibit 2 outlines the application of VSM across diverse industries, with a particular emphasis on the challenges encountered and the insights derived from the case studies as detailed by the authors.

VSM can successfully be used in knowledge work environments of different industries such as the construction, aircraft, and service industries. However, the specific VSM method depends on the case. Various researchers have applied VSM by evaluating metrics such as process cycle efficiency, processing time, lead time, and by focusing on enhancing value-added activities (VA) while reducing NVA activities following the original VSM methodology used in the manufacturing environment (Stadnicka & Chandima Ratnayake, 2015). Other authors have made conclusions based on the examination of the current state of the VSM observation without performing precise calculations (Riezebos & Huisman, 2021). All analyzed case studies described in Exhibit 2 resulted in improved performance owing to VSM, regardless of the implemented methodology.

Numerous authors have effectively outlined methods for implementing VSM within a knowledge work environment (Ali et al., 2015; Arbulu et al., 2003; Chen & Cox, 2012; Chadha et al., 2012; Claire et al., 2013; Dogan & Unutulmaz, 2014; Fashtali et al., 2016; Marin-Garcia et al., 2021; Mayrl et al., 2013; Ratnayake & Chaudry, 2015; Stadnicka & Chandima Ratnayake, 2015; Schulze et al., 2013; Tuli & Shankar, 2015; Torres et al., 2018; Tyagi et al., 2015; Vidal- Carreras Pilar et al. 2015). Most case studies related to knowledge work have been performed for the construction (Torres et al., 2018) and health service (Marin-Garcia et al., 2021) industries. There is lack of detailed case studies for education (Riezebos & Huisman, 2021), hospitality (Schroeder, 2017) and engineering industries (Tyagi et al., 2015).

The need for employing digital VSM

The manual execution of VSM, is increasingly proving inefficient, primarily due to the escalating complexity of products (Horsthofer-Rauch et al., 2022). Despite organizations' attempts to implement digital technologies for process enhancement (Adomako & Nguyen, 2023), there is currently a lack of literature regarding the implementation of digital VSM in knowledge work organizations. The existing literature primarily focuses on the potential of digital VSM within the manufacturing sector only (Knoll et al., 2019; Sullivan et al., 2022; Trebuna et al., 2019; Urnauer et al., 2021).

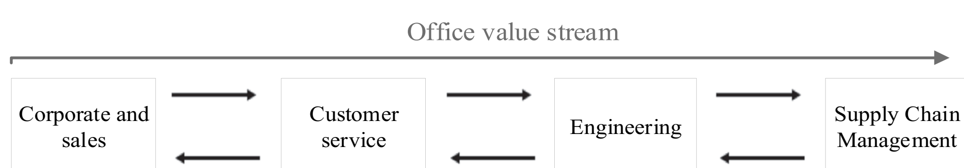

Exhibit 1. Office VS (Keyte and Locher 2015)

Exhibit 2. Use of VSM in different industries.

Industry	Challenges	Findings from case studies	Reference
Construction (supply chain, administrative management, construction processes, and designing)	• Uncertainty in time estimates to execute design. • Lack of linearity in activities. • Disruption of focus. • Difficulty in prioritization. • Coordination and scheduling challenges. • Impact on quality and consistency. • Adapting to unforeseen circumstances.	• Communication enhancement among team members through VSM. • Reduction in waiting time for information. • Creation of a design procedure database and checklists. • Supply chain improvement focus.	Shou et al. (2017); Torres et al. (2018); Arbulu et al. (2003); Pasqualini and Zawislak (2005); Ogunbiyi et al. (2014).
Aircraft (business process)	• Inefficiencies present in the quotation preparation process of the manufacturing process.	Identified reasons for inefficiencies through VSM such as: • Request of unspecified details from customers. • Unclear demands from customers. • Delays affecting process efficiency.	Stadnicka and Ratnayake (2015)
Electrical	• High defect rate in the electrical design process and high labor costs due to rework.	Several non-valuable activities identified: • Waiting for customer feedback and for the manual delivery of documentation. • Excessive and unused design documentation. • A combination of VSM with root cause analyses and the 5 Whys method improved the overall process performance by enabling faster and systematic task tracking and reducing labor costs.	Chen and Cox (2012)
Engineering and industrial design (product development)	• Excessive complexity of the traditional process flow map.	Using product development VSM (PDVSM) decreased waiting times and reduced iteration steps. Other benefits: • Lower development costs • Reduced manpower hours and shorter cycle times	Ali et al. (2015); Tuli and Shankar (2015); Mayrl et al. (2013); Schulze et al. (2013); Tyagi et al. (2015).
Service industry	• Time consuming sales process.	• Time devoted to non-value-added (NVA) activities. • Challenges in sales process measurement. • Reliance on tracking systems with data entry requirements. • Limited efficiency in price negotiations.	Barber and Tietje (2008)
Hospitality	• Unneeded activities performed by service personnel. • Unnecessary movements. • Unneeded time-consuming formulas.	• VSM facilitated identification of numerous improvement opportunities. • Elimination of waste through VSM implementation. • Reduced costs associated with service delivery. • Decrease in the time required to deliver services.	Schroeder (2017)
Healthcare, public service	• Long waiting time of patients. • Medical errors.	Utilising VSM combined with queuing modelling led to: • Reduction in employee overtime. • Fewer customer complaints in the administrative process. • Reduced treatment time. • Eliminated delays, errors, and inappropriate procedures. • Improved customer satisfaction.	Marin-Garcia et al. (2021); Vidal- Carreras Pilar et al. 2015; Fashtali et al. (2016); Dogan and Unutulmaz (2014); Claire et al. (2013); Chadha et al. (2012), Tortorella et al. (2022)
Educational sector	• Stressful working environment.	• Empowerment of teachers. • Reduction of work stress. • Facilitation of improvement initiatives. • Attention to non-quantitative observations. • Modified VSM approach for knowledge workers.	Riezebos and Huisman (2021)

Horsthofer-Rauch et al. (2022) suggest that digitalizing data collection and VSM creation is essential in manufacturing case studies. Process mining can complement digital VSM by analyzing and modeling processes, addressing efficiency challenges. Despite promising approaches for cost-effective digital VSM implementation, its full adoption in industrial settings remains unrealized (Sullivan et al., 2022).

Companies increasingly offer software solutions for digital VSM generation, expediting the process with interactive tools (Larsson et al., 2023). This approach saves time by predesigning symbols and allows for iterative map improvements and multiple future revisions. Sharing maps via online platforms facilitates feedback from all employees, particularly beneficial for knowledge workers, who can access and provide feedback on stored VSMs at any time (Larsson et al., 2023).

Sustainable VSM Approach to Knowledge Work

Several studies have expanded the scope of VSM to incorporate sustainability criteria (Faulkner & Badurdeen, 2014; Kihel et al., 2022; Larsson et al., 2023). Following the Triple Bottom Line (TBL) concept, the sustainability of office processes can be assessed from three perspectives: environmental health, economic viability, and social well-being (Elkington & Robins, 1994; Norton et al., 2021). Below are examples from a literature review on waste from a sustainability perspective,

Exhibit 3. Waste relating to the knowledge work from a sustainability perspective.

Waste type	Description of waste	TBL pillar	Improvement initiative	Reference
Transportation (waste related to transport of goods)	Transporting individual products, unnecessary transportation that could be mitigated with better planning, and the overall movement of products and materials that were not required.	Environmental sustainability	Encouraging sustainable transportation (public transportation, biking); transportation of several products at one time, using sustainable transport providers.	Larsson et al. (2023)
Energy consumption	Energy use for lighting; high levels of artificial light (negative effect on human health, difficult sleeping and lover vitality).	Environmental & societal sustainability	Using focused illumination in task areas; lower levels of lighting in surrounding and background areas, maximizing the availability of natural light.	Norton et al. (2021), Peeters et al. (2021)
	Energy used for air condition.	Environmental sustainability	Reduce heating-related energy consumption through modern HVAC systems, understanding impact of solar radiation.	Nagarathinam et al. (2017)
	Energy used for power supply for computers, printers, refrigerators, coffee machines.	Environmental sustainability	The heat generated by electronics can be used to heat up the office if buildings has a sensor to stop the HVAC heating.	Norton et al. (2021)
Water consumption	Water used for dishwashers, bathrooms.	Environmental & economic sustainability	Installing water saving devices in bathrooms, installing water efficient dishwashers.	Tijs et al. (2017)
Emissions	Carbon dioxide emission.	Environmental sustainability	Deploying green certifications such as LEED for sustainable buildings to reduce carbon dioxide emission about 34%.	Bernoville (2023)
Lack of biodiversity	Indoor air quality, workspace colour schemes, interior plants, dust levels and biological contaminations, indoor carbon dioxide concentration affects affect employee health and productivity.	Environmental & societal sustainability	Interior living plants provide stress-reducing benefits. Natural environments have a restorative effect on attention.	Kamarulzaman et al. (2011)
Materials	Paper waste, overconsumption of paper.	Environmental & economic sustainability	Digitise all files, forms, print on both sides on paper, reduce reports size.	Shah et al. (2019)
Garbage	Typical office garbage: office equipment (printers, futniture, gadgets, electrical equipment), miscellaneous waste (plastic bottles, plastic food boxes).	Environmental & economic sustainability	Recycle garbage, use glass instead of plastic for food, purchase durable electrical equipment.	Hopewell et al. (2009)

Exhibit 10. Data required for the calculation of takt time (planned takt time)

	Available working time (initial)				
Task responsible	Sales	Pre-Engineering	Engineering	Customer demand	Takt time
Document controller	N/A	N/A	15 h	1	15 h per task
Sales Manager	15 h	N/A	N/A	1	15 h per task
Project Manager	22.5 h	22.5 h	15 h	6	10 h per task
Electrical Engineer	15 h	67.5 h	105 h	10	18.5 h per task
Automation Engineer	15 h	52.5 h	50 h	6	19.5 h per task
Mechanical Engineer	N/A	N/A	105 h	3	35 h per task
Purchaser	N/A	15 h	15 h	5	6 h per task

Exhibit 11. Data required for the calculation of takt time (final takt time).

	Available working time (initial)				
Task responsible	Sales	Pre-Engineering	Engineering	Customer demand	Takt time
Document controller	N/A	N/A	15 h	1	15 h per task
Sales Manager	15 h	N/A	N/A	1	15 h per task
Project Manager	22.5 h	22.5 h	15 h	6	10 h per task
Electrical Engineer	15 h	80.5 h	140 h	10	23.5 h per task
Automation Engineer	15 h	52.5 h	50 h	6	19.5 h per task
Mechanical Engineer	N/A	N/A	165 h	3	55 h per task
Purchaser	N/A	15 h	15 h	5	6 h per task

specifically relating to the knowledge work environment, accompanied by improvement initiatives.

When considering knowledge work processes, there is limited literature addressing waste from the perspective of the TBL concept. However, individual case studies focusing on specific types of waste in office environment can be found. For example, research has been conducted on energy consumption in office buildings (Norton et al., 2021; Peeters et al., 2021), carbon dioxide emissions (Bernoville, 2023), and the impact of lack of biodiversity and windows in employee physical conditioning areas (Kamarulzaman et al., 2011). Most authors predominantly describe waste related to the economic and environmental pillars, often overlooking the societal pillar. Another observation is the shortage of literature on cases of

VSM in knowledge work processes, as authors mainly concentrate on production processes.

The Synergy Between Lean and Green Practices

Combining lean and green practices promotes sustainability by merging lean's focus on cutting NVA activities with green's priority on reducing resource consumption and environmental impact (Abualfaraa et al., 2020; Kosasih et al., 2023; Queiroz et al., 2023). Studies by Verma et al. (2021) and Verma and Sharma (2016) highlight that tools like Energy VSM (EVSM) and entropy assessments are key in pinpointing and minimizing waste in both materials and energy. This lean and green approach enhances operational efficiency, cuts environmental impact, and aligns economic, environmental, and social goals in manufacturing systems (Kosasih et al., 2023). The lean & green approach is increasingly gaining popularity and is anticipated to see substantial growth in scholarly literature (Elemure et al., 2023).

Case Study

Description of Case Study

The case study was performed in a medium-sized electrical engineering company in Stavanger, Norway, which is an ETO organization. The company has approximately 41 employees and provides knowledge work (i.e. engineering and project management), services, and manufacturing to following industrial sectors: offshore, defense, marine, aquaculture, and the shore power industries. This study is dedicated exclusively to knowledge work and non-manufacturing activities within the company. The investigation of the project portfolio included 18 projects: 13 surpassed the planned budget, and 14 exceeded the scheduled engineering time (Figure 4a, b). The conclusion was that, for the majority of projects, the final project margins were considerably lower than the initially estimated margins. The top managers of the company concluded that the exceeded engineering time was the main reason for the low project margins.

The project selected for analysis is a typical example from the shore power industry. Its selection is based on its representativeness, as it mirrors the common projects undertaken by the company. Consequently, its analysis results can be generalized to compare with other projects executed by the company. The chosen project was analyzed using VSM. The interviewed project members (i.e. knowledge workers) discussed mainly the selected project; however, the majority of participants often expressed their opinions and observations related to other projects executed within the organization. Their opinions are presented in this paper. The purpose of the VSM analysis

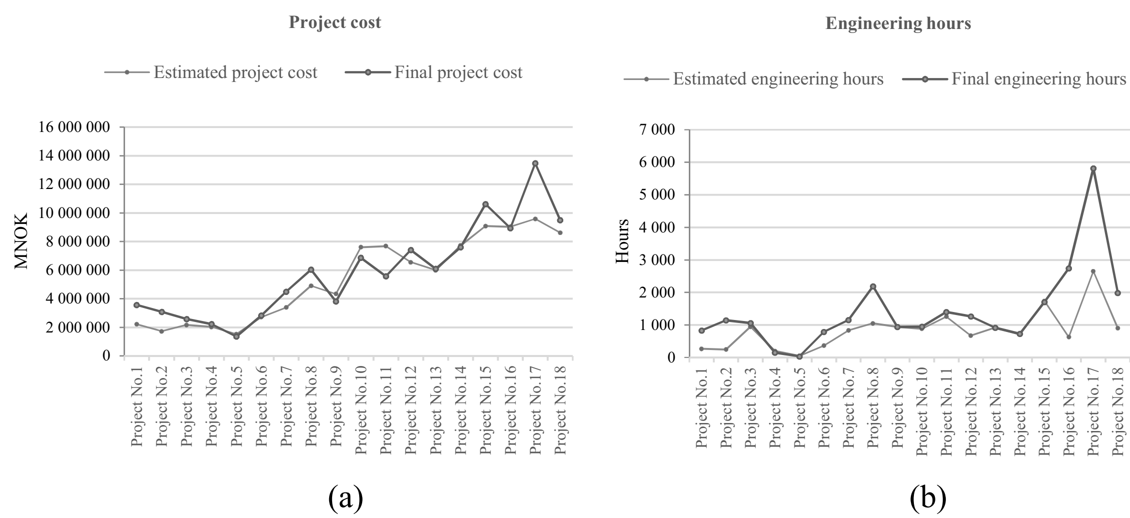

Exhibit 4. (a) Comparison of Estimated Project Costs versus Final Project Costs for All Analysed Projects; (b) Estimated Engineering Hours versus Actual Engineering Hours for All Analysed Projects

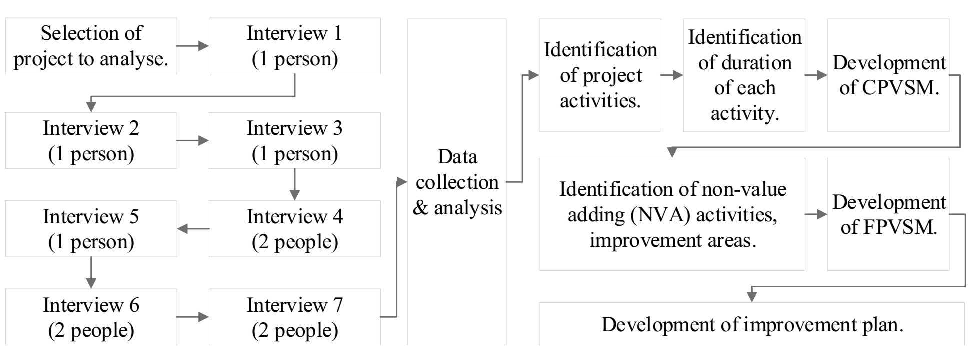

Exhibit 5. VSM Methodology

was to assess the workflow within the administrative environment and pinpoint the specific causes for the extended engineering time in projects.

VSM Process Design for Knowledge Work

Figure 3 presents the detailed methodology for the VSM process, adapted from the model developed by Rother and Shook (1999). The foundational model consists of four main steps: selecting a product family, creating a current state map, designing a future state map, and developing an implementation plan for the future state (Rother & Shook, 1999).

The proposed method aims to offer a structured approach to applying lean philosophy in engineering projects, with an emphasis on knowledge work. Furthermore, the approach aims to identify improvement opportunities within project processes for improving the knowledge work performance in future projects. The presented VSM method focuses mostly on information flow and waste. The strict measurements of time or quality related to knowledge work tasks cannot be automatically gathered from the company's IT systems; therefore, the VSM main source is interviews. Initially, the individual tasked with overseeing VSM selected a project for analysis and assembled a VSM team comprising various knowledge workers. The team consisted of a project manager, a vice president project executive, as well as specialists such as an automation engineer mechanical engineer, electrical engineer, service technician, document controller, production technician and purchaser. The data collected during the VSM process underwent analysis and are allocated in the subsequent sections through the current project value stream map (CPVSM) and future project value stream map (FPVSM). The CPVSM was created by closely tracing the actual flow of materials and information. Due to the project's complexity, the VSM lead conducted individual interviews with team members to gather details on activities within each discipline. Interviewees described their contributions to the current state of the BP, highlighting issues, sharing improvement ideas, and identifying areas of waste within the CPVSM based on their experiences. 'Waste' was defined as any process, process step, or process product such as an e-mail, a document, and data that do not contribute to the organization's success (Conger, 2010).

After the interviews concluded, the individual overseeing VSM compiled a comprehensive CPVSM utilizing the gathered data. All improvement suggestions and issues pinpointed by team members were incorporated into the diagram using designated symbols (Exhibit 4). Finally, a comprehensive analysis was conducted, concentrating on eliminating waste like excessive waiting times (Exhibit 5). The challenges identified during the development of the CPVSM were addressed with solutions and subsequently presented in the FPVSM (Exhibit 6).

During the interviews, participants were given two options for creating VSMs: using pen and paper method or inputting data into Microsoft Visio software. It was noted that the majority of interviewed persons preferred utilizing Microsoft Visio, where one person took on the responsibility of mapping the process while the interviewee provided information about it. On the other hand, for workshop employees, the pen and paper solution was chosen. Subsequently, the data gathered from the interviews was electronically saved as both a Microsoft Visio file and PDF format. These files were then made accessible to the company's employees on a shared platform, ensuring that everyone had access to the CPVSM and FPVSM.

The sustainable evaluation of the VSM was conducted after the collection of interview data. This assessment was solely based on information derived from the literature review.

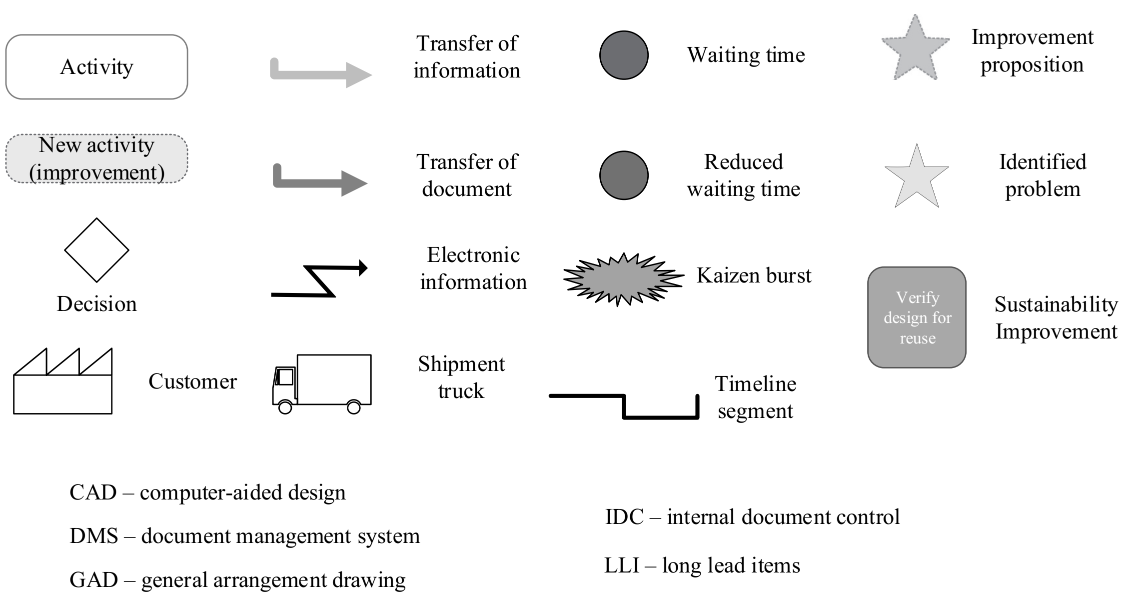

Exhibit 6. Legend for VSM (Larsson et. al 2021)

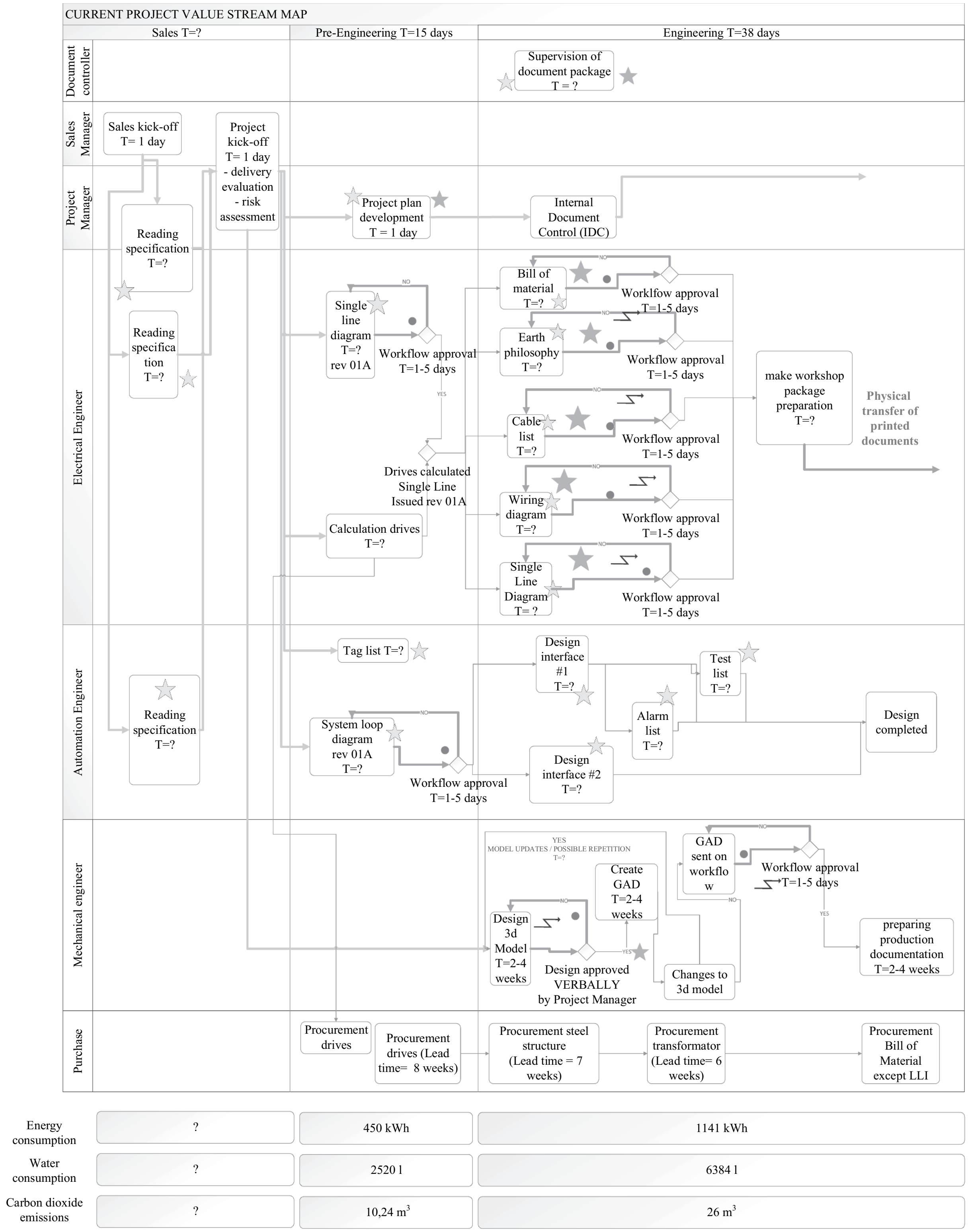

Exhibit 7. Current Project Value Stream Map (CPVSM) featuring identified issues and proposed improvements: case study (adapted from Larsson et al., 2021).

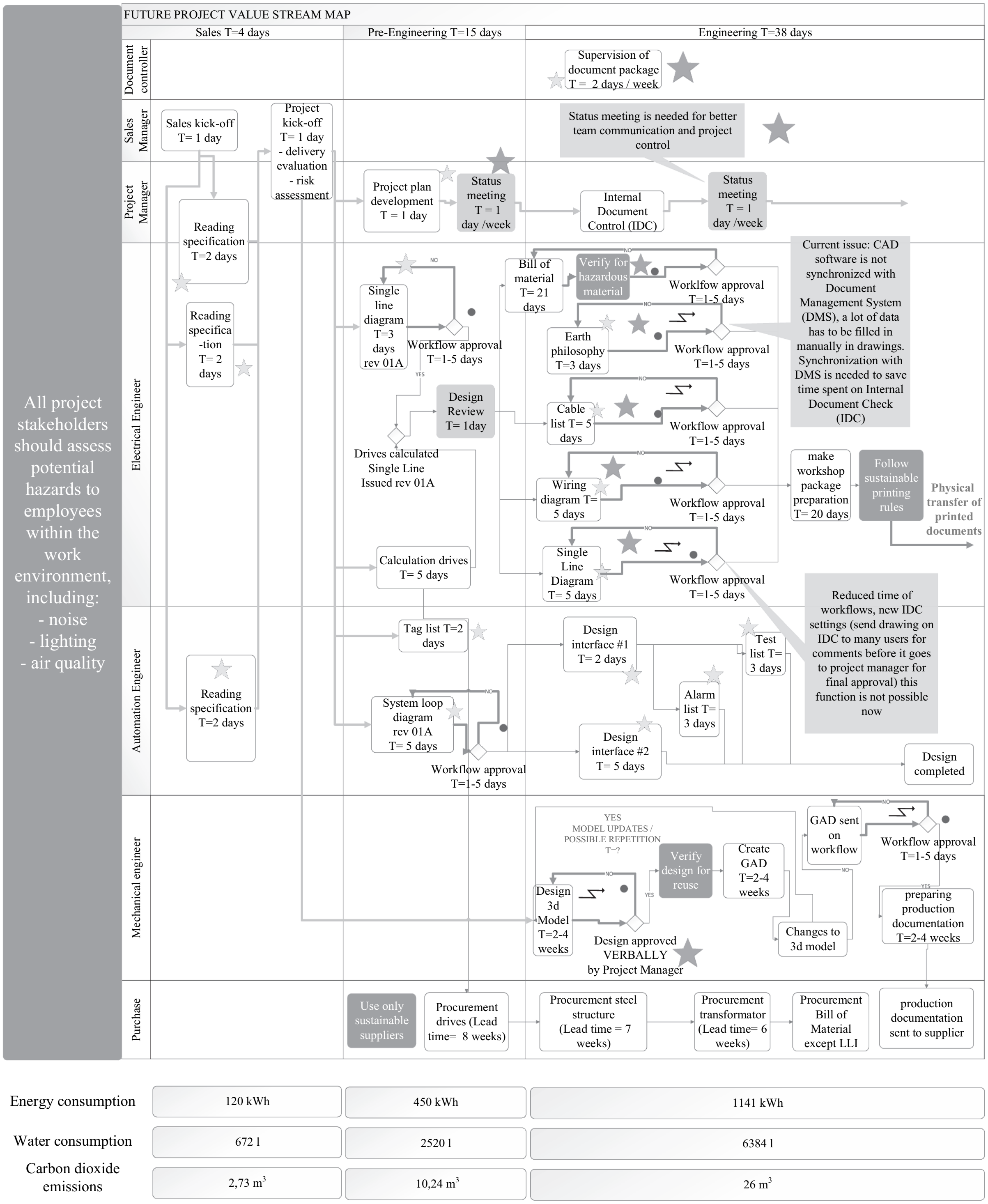

Exhibit 8. Future Project Value Stream Map (FPVSM): case study.

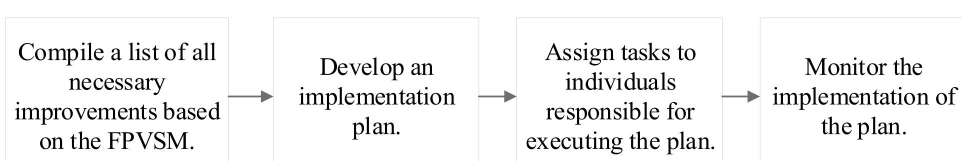

Exhibit 9. Implementation plan.

The assumptions for the sustainability analysis are as follows:

- Ten individuals are participating in the VSM process (as indicated in Figure 5).
- Water consumption per employee is defined as 24 liters used per one working day, based on the study conducted by Hunt et al. (2011).
- Energy consumption per employee is determined as 4,29 kWh per one working day based on research conducted by Murtagh et al. (2013).
- Carbon dioxide emissions per person during working hours are defined as 0,013 m^3 per hour based on the data provided by The Engineering ToolBox (2004).

To ensure that all improvement proposals had been documented and implemented, an implementation plan was developed (Figure 7).

Takt Time in the Office Environment

Takt time in the office environment can be determined following the methodological guidelines outlined in recent studies (Ding et al., 2024; Khalil et al., 2024). The calculation adheres to the standard formula:

$$Takt\ Time = \frac{Available\ Work\ Time}{Customer\ Demand}$$

Calculating takt time for engineering projects presents several challenges compared to traditional manufacturing settings (Ding et al., 2024). These challenges include for example complexity of multitasking, and fluctuations in task duration depending on the project phase.

In the case study, the company manages a portfolio of projects with varying lead times. For the project analyzed in this study, the customer required the product to be delivered within three months of signing the contract. A notable characteristic of this project was the overrun of initially planned working hours by its completion. The sales team initially planned the project with an allocation of 4 days for sales, 15 days for the pre-engineering phase, and 14 days for the engineering phase. Takt time was calculated based on the initial estimates (Table 3). For instance, the electrical engineer's workload was distributed as follows: 15 hours in the sales phase, 67.5 hours in the pre-engineering phase, and 105 hours in the engineering phase. The electrical engineer was responsible for completing 10 tasks, resulting in a calculated takt time of 18.5 hours per task.

Following the project's execution, actual time allocations deviated from the initial plan. The engineering phase extended to 38 days, while the pre-engineering phase remained at 15 days (Table 4). For instance, the electrical engineer's working time increased to 80.5 hours in the pre-engineering phase and 140 hours in the engineering phase. Despite continuing to handle 10 tasks, the engineer's takt time increased to 23.5 hours per task, reflecting the prolonged project timeline and the higher demand on engineering resources.

Both the initial and final takt times are compared in Figure 8a, while the identified bottlenecks are illustrated in Figure 8b.

The comparison in Figure 8a reveals that roles such as the sales manager, document controller, project manager, and purchaser either maintained their planned takt times or experienced only minor deviations, indicating that these roles likely did not contribute significantly to the project's delays. However, the primary bottlenecks were observed in the tasks assigned to the mechanical engineer and electrical engineer. Addressing these inefficiencies, potentially through improved resource allocation or process optimization, could enhance the efficiency of future projects and mitigate delays.

Results and Lessons Learnt by Respective Managers

Analysis and Diagnosis of the Current State

Following the analysis of data conducted through the FPVSM, separate graphs were established for VA activities, NVA activities, and non-value-added but necessary (NNVA) activities within the context of knowledge-based work (Figure 9).

VA activities are defined as those that directly contribute to the enhancement of the final product (Jones, 2018; Smith & Johnson, 2020). Examples of VA activities include engineering design (Wibowo & Deng, 2020) and engineering calculations (Bernard et al., 2010). However, engineering design may also be classified as NVA depending on its final contribution to the project. Several scholars have examined the concept of value in engineering design activities, introducing terms such as "value-driven engineering design," which emphasizes the importance of maintaining a value-focused approach to ensure that engineering design qualifies as a VA activity (Bertoni et al., 2017). Conversely, time spent on engineering design that results in overly detailed, unnecessary documents with no customer benefit, or designs containing errors that necessitate rework, is considered NVA (Emuze et al., 2014).

NNVA activities include tasks like creating BOMs, conducting sales kickoff meetings, developing project plans, or awaiting approval of drawings. While these activities do not add direct value to the final product, they are essential for operational functions and project management. NVA activities include tasks such as, waiting for others to provide information, addressing errors from previous process steps, or unproductive meetings.

In projects, time is often allocated to "searching for information," such as identifying material properties, locating suppliers, or reviewing regulatory standards. This activity can be classified as VA, NVA, or NNVA, depending on its context (Braglia et al., 2006; Hoppmann et al., 2011; Jørgensen & Emmitt, 2008). For instance, it is categorized as VA when the information is critical for task completion and directly contributes to the final output, NVA when it becomes redundant due to inefficiencies such as disorganized documentation, and NNVA when required for compliance purposes, even though it does not directly enhance the product.

The graphs (Exhibit 9) were created by summing the times of individual activities. Furthermore, as shown in Figure 9b, NNVA activities relates to 'waiting for approval of drawings' (64%), 'reading specifications,' (20%) and 'waiting for approval

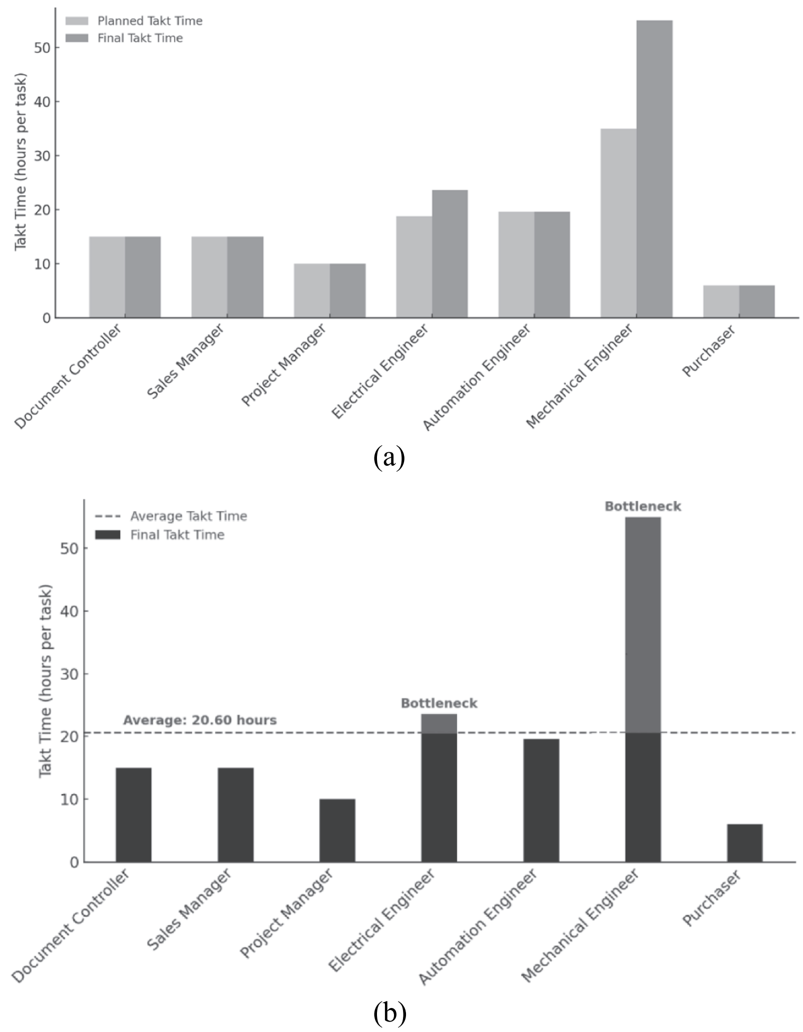

Exhibit 12. (a) Comparison of planned versus final takt time; (b) Final takt time with bottlenecks highlighted.

of documentation' (16%) which, while time-consuming, are essential for ensuring that valid and approved documentation is in place to support the creation of a valuable product. Implementing strategies such as clearly defining approval criteria, utilizing parallel review processes, empowering team members, providing training, and continuously improving processes will lead to reduced NNVA.

One of the primary factors contributing to the extended engineering time was the interviewees' inability to accurately estimate the duration required for various engineering activities. These activities were primarily associated with the generation of designs and documentation, encompassing tasks such as drafting single-line diagrams and compiling bills of materials. The CPVSM shows that the for several years implemented document management system (DMS) was not fully compatible with the needs of the engineering teams. The engineers mentioned technical problem related to issuing new documentation and the need to perform a lot of manual work in order to create new revisions of documents. The technical problem occurred mainly during the creation of drawings such as system loop diagrams, which are multidisciplinary documents showing different variables in an engineering system and their interrelations. This drawing is typically sent to several other engineers (electrical automation engineers) for a check before the final revision can be sent to the technical project manager and, finally, the customer. The VSM results show that the DMS was not designed for this step and that the drawing could not simultaneously be sent to several engineers. In this case, most of the drawings were printed out on paper and passed on among engineers; respective knowledge such as comments on the drawing or red marks were not saved. Additional challenges identified through VSM included the following: inadequate engagement of the document controller in the project process, evidenced by the absence of oversight concerning the project document list and engineering documentation; undocumented procedures concerning knowledge and experience transfer, notably in design reviews; and the absence of documented project milestones, such as design freezes within the 3D model.

Moreover, the insufficient control of the project management over engineering activities and the development of documentation was one of the most important problems (for example, the lack of documented project status meetings and document status reports). Some of the interviewed engineers admitted that the follow-up project status meetings were not organized often enough by project managers. The engineers

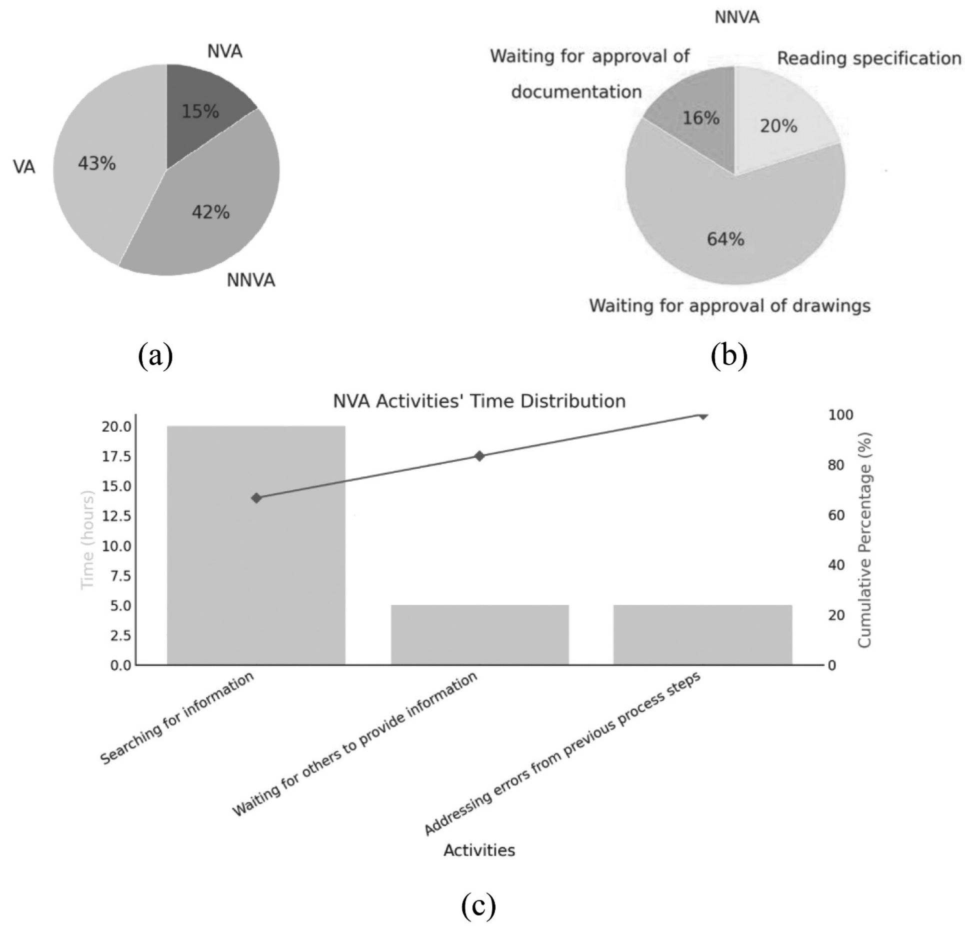

Exhibit 13. Percentage of VA, NVA and NNVA activities' time distribution and (b) Percentage of NNVA activities' time distribution; (c) Pareto Analysis for of NVA activities' time distribution.

also revealed that some of the project status meetings did not have a defined agenda or scope; therefore, it was impossible to prepare for the meeting in advance.

The evaluation of green practices in the office environment

The engineering department displays a pronounced deficiency in prioritizing sustainability, particularly with regard to the selection and utilization of sustainable materials. The application of design for reuse is inconsistent across projects; although some projects incorporate reuse principles, a considerable number do not regard it as a mandatory component, underscoring a lack of uniformity in its implementation. Additionally, critical sustainability considerations are routinely excluded from operational checklists, and there is an excessive amount of unregulated printing, with insufficient oversight regarding paper consumption. Moreover, design practices are not aligned with sustainability goals, as engineering drawings often exhibit inefficient paper usage, leaving substantial blank spaces, which reflects a lack of intentional focus on paper conservation during the design process.

Additionally, office lighting levels are not proactively monitored or optimized; adjustments are typically only made in response to complaints, indicating a reactive rather than proactive approach to energy efficiency and workplace environmental conditions. Despite sufficient unoccupied space in the office, only two plants were present, highlighting a missed opportunity to enhance both aesthetics and indoor air quality through the addition of more greenery.

Future State Maps

The overall findings suggest that the engineering control and monitoring procedures within projects require improvement. If the project managers had an established routine for systematic and formal project follow-up meetings, most of the issues discovered during the VSM process would have been noticed earlier (because they would have been recorded in the formal meeting document, and proper actions would have been taken). As the meetings had usually not been documented, the comments and observations had been forgotten.

Engineers lacked the ability to estimate the time required for standard engineering tasks, leading to uncertainty in project timelines. To address this, project managers should collaborate closely with engineers to plan project activities, ensuring clarity on project timelines. Implementing the Last Planner System (LPS), look-ahead planning, and weekly planning can enhance project scheduling, with look-ahead planning focusing on tasks like 3D modeling and purchasing long lead items, and weekly planning facilitating commitment to tasks. This integrated approach can create a controlled work environment and improve engineering project performance.

Additionally, several sustainability improvements have been incorporated into the process. The first improvement proposition pertains to all employees, who should focus on observing and evaluating potential hazards in their working environment, such as high noise levels, inadequate or excessively strong lighting, or poor air quality. During the design process, engineers should focus on verifying the sustainability of the design, for example, by identifying hazardous substances in the BOM or assessing the design's potential for reuse in the future. Moreover, engineers need to prioritize designing documentation with the goal of minimizing paper usage, particularly in the case of fabrication drawings, and preferably digitizing all documentation for fabrication purposes. Additionally, purchasers should verify whether suppliers and vendors offer sustainable services, and preference should be given to those offering sustainable transportation or products.

Recommendations for Implementing the Future State

To improve performance during projects, monitoring of all activities in the pre-engineering and engineering phases must be intensified; these activities are mainly activities related to reappearing processes such as the creation of document revisions and designs. It should be noted that the BPs described in the case study organization 'handbook' did not align with the activities and phases described by the interviewed team members. Most of the interviewed engineers admitted that the BP description available on the company's website does not provide enough guidance when it comes to the performance of tasks and responsibilities as the descriptions of specific tasks or activities are either 'too complicated,' 'not realistic,' or 'missing.' This should be a clear sign for operation managers to re-engineer the BPs to make them functional.

A VSM process would be useful for improving the organization's BPM as it would visualize the actual BPs and improve the process performance by identifying waste and improvement areas. When knowledge work is presented as a process, it helps knowledge workers contribute discipline and structure in daily tasks. The cooperation during the assessment of the project performance can also help knowledge workers; the emphasis on collaboration gives the group a common goal and purpose. Operation managers should share the strategic values with employees. According to Kling (2000), a transparent process structure (i.e. the process phases and their connections) and transparent performance regarding customer satisfaction, duration, cost, and quality are '*absolutely essential in order to find the weaknesses and optimisation possibilities in the process.*'

Understanding "lean and green" practices

The integration of lean and green practices in office processes shall focus on improving efficiency while minimizing environmental impact. Lean principles, such as 5S (Sort, Set in order, Shine, Standardise, Sustain) and continuous improvement (Kaizen), streamline workflows by reducing waste and improving task flow. When combined with green initiatives, these practices also reduce the office's ecological footprint by lowering energy consumption, minimizing paper use, and optimizing resource efficiency. For example, digitizing documents and using eco-friendly materials can help achieve both operational and environmental goals. This synergy creates a more efficient, cost-effective, and environmentally conscious office environment, contributing to overall sustainability objectives.

Practical Implications for Engineering Managers

Engineering managers can leverage the VSM methodology to address inefficiencies and enhance workflow efficiency in knowledge-intensive projects, with an emphasis on minimizing waste and optimizing resource utilization. Facilitating interdepartmental collaboration and implementing structured, well-documented project reviews can significantly improve oversight and enable the timely resolution of issues. Accurate estimation of task durations should be prioritized, with tools such as the LPS employed to enhance project scheduling and maintain control. Revising and standardizing business processes, addressing outdated procedures, and establishing clear project milestones help to mitigate ambiguity and strengthen accountability mechanisms. Incorporating "lean and green" strategies, including the digitalization of documentation and the adoption of environmentally sustainable design practices, fosters both operational efficiency and environmental responsibility. Embracing digital tools for process visualization and ensuring the integration of systems with engineering workflows reduces manual labor while safeguarding institutional knowledge. Finally, promoting transparency in performance metrics and aligning individual contributions with organizational objectives facilitates continuous improvement and enhances project outcomes.

Discussions

The VSM method employed in this study can be compared to VSM4EDU, as proposed by Riezebos and Huisman (2021), owing to its reduced symbols compared to methods utilized in industries such as construction (Shou et al., 2017). Analogous to the educational sector, this study primarily concentrates on unquantifiable observations, problems, and identified opportunities for process improvement. The study yielded results consistent with prior research in the construction industry (Shou et al., 2017; Torres et al., 2018). Key recurring topics included: uncertainty regarding the time required for team members to execute design tasks, a lack of linearity in activity progression, and shifts in focus during the execution of tasks.

A study conducted by Chen and Cox (2012) identified activities such as waiting for documentation approval or decision-making as NVA. In contrast, we classified these activities as NNVA. Despite this difference in classification, reducing the duration of such activities remains beneficial, as it has the potential to significantly enhance overall process efficiency. This distinction emphasizes that, regardless of the specific category, reducing unnecessary delays contributes positively to streamlining processes and improving productivity. Similar to the VSM analysis conducted for the product development sector, this study demonstrated that VSM can be highly complex, leading to difficulties in creating a VSM map due to many interactions. In alignment with the findings of Schroeder's research (2017), enhancing the planning and monitoring of activities by managers was considered essential for improving the performance of the process.

This paper builds on prior research by Kosasih et al. (2023), which highlights the synergy between lean and green practices in non-manufacturing processes. Aligning with the findings of Ferrazzi et al. (2024), this study agrees that integrating lean and green practices can significantly improve both environmental sustainability and operational performance in office settings.

Conclusions

The concept presented in this paper builds on prior research studies of knowledge work in which VSM was successfully used to improve performance during engineering projects and processes. This research study, which is based on a case study, describes how VSM in the engineering office environment can help organizations and managers. The results of this study help project and operation managers effectively apply VSM in their organizations to improve the performance of their engineering teams.

The case study findings indicate that overall project performance can be enhanced by minimizing NVA activities, such as waiting times. Additionally, better control over the duration of engineering tasks can be achieved through detailed task planning and regular follow-ups. The enhancements proposed by VSM have the potential to reduce project duration by minimizing delays and addressing engineering design flaws. Furthermore, enhancing administrative routines and restructuring documentation processes can foster knowledge sharing among project stakeholders.

The proposed improvement areas are similar to those implemented in sectors like manufacturing, construction, healthcare, and product development, where VSM has reduced production lead times and enhanced process efficiency by eliminating waste, such as extended waiting times and excess labor hours. However, the findings and suggested improvements from this case study can only be compared to those from other sectors and industries, as there is limited research on VSM in office-based knowledge work within engineering companies. While each sector has unique characteristics that limit direct comparisons of VSM outcomes, the systematic VSM approach outlined in this paper is adaptable for improving efficiency in any organizational office environment.

Subsequent investigations will concentrate on lean methodologies and tools that complement VSM within knowledge-based work settings, the explanation of common inefficiencies in office-based tasks, and the determinants fostering effective implementation of CPVSMs and FPVSMs. The results of future research studies may be useful for other fields of knowledge work. The case study is related to project execution with the main focus on engineering design processes in a medium-sized electrical company. Different VSM approaches may be needed for different types of designs and product volumes (e.g. prototypes or serial production). Larger companies may experience different challenges during communication and remote operations and while outsourcing design departments.

This study has several limitations. First, the research was conducted in a Norwegian company, and the results may not be generalizable to other countries due to potential cultural differences. Second, the study focused on an electrical company serving specialized customers, which may limit the applicability of the findings to other electrical companies with different customer profiles and project requirements. Finally, the company's size presents another limitation. The results may vary across organizations of different sizes, as factors such as operational processes are likely influenced by organizational scale.

The overall findings contribute to academic understanding by reinforcing the applicability of digital VSM in non-manufacturing settings, such as engineering knowledge work. The effective implementation of digital VSM in engineering knowledge work can be supported by integrating digital collaboration platforms for real-time document sharing and tracking, redesigning document management systems to reduce manual work and enhance compatibility with tasks, and adopting structured project management practices. Industrial practices can benefit through actionable recommendations for integrating lean principles, addressing inefficiencies, and promoting sustainability. These align with prior research emphasizing the synergy between lean and green practices in improving both environmental and operational performance.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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Daria Larsson is a highly skilled professional specializing in engineering and management, with extensive experience in operational excellence, project leadership, and sustainable manufacturing practices. Currently pursuing a Ph.D. in offshore technology, her career includes significant contributions in project management and engineering roles within the energy and manufacturing sectors. Daria's academic background includes a master's degree in management and engineering qualifications in civil and structural engineering, showcasing her expertise in both technical and strategic domains.

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