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Kristian Kleimola

Modern standardization capabilities & impact in Lean 4.0 maturity development

Roles as smart manufacturing foundation

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Author:	Kristian Kleimola
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ABSTRACT:

This thesis examines the role and impact of modern process standardization in developing Lean 4.0 maturity, which combines the paradigms of the operational waste-eliminating Lean philosophy and modern and digital smart manufacturing, known also as industry 4.0 technologies. Research regarding this perspective is at the time of this thesis non-existent, and thus the objectives set were to find how standardization affects progressing in Lean 4.0 maturity, and how modern standardization capabilities, namely that of modern technology-integrated tools, can improve these effects. The research was conducted as a case study, combining analysis of multiple perspectives, namely that of a case company undergoing a Lean transformation leading to smart manufacturing implementation, capability assessment of an industry 4.0-integrated Lean standardization tool, descriptive and correlational statistical analysis of survey data regarding Lean maturity development factors, and a pilot test conducted at the case company in the assessed Lean standardization tool. Findings of the research indicated that standardization affects progressing in Lean 4.0 maturity by serving as a foundation for fundamental operational changes by commonizing operating procedures and thus supporting performance stabilization, after and by result which it supports operational improvements by benchmarking performance and sustaining made changes. The assessed Lean standardization tool had multiple modern technologies to streamline the standardization process, its visual presentation, and posting the standards at the point of use, all enabling communal contribution to standardization practices thus upholding organizational engagement, recognition, and problem solving, all essential principles of Lean organizational culture. In addition, the industry 4.0 integrations of the Lean standardization tool contribute to a gradual deployment of smart manufacturing technologies, thus cultivating associated awareness, communication, and challenges diagnostic. As a related vital factor, leadership and adequate training were found correlated factors to both successful Lean developments as well as that of successful adoption of the assessed Lean standardization tool and its industry 4.0 capabilities, in both as a mitigant of resistance to change. Overall, the findings of this thesis suggest a Lean-emphatic approach to Lean 4.0 initiatives, where Lean and gradual industry 4.0 technologies in its aid are implemented before major smart manufacturing implementations.

KEYWORDS: Standardization, Lean, Lean 4.0, Industry 4.0, smart manufacturing, maturity

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TIIVISTELMÄ:

Tämä pro gradu -tutkielma tarkastelee modernin prosessistandardoinnin roolia ja vaikutuksia Lean 4.0 -maturiteetin kehittämisessä, joka yhdistää operatiivista hukkaa poistavan Lean-filosofian ja älykkään tuotannon eli Industry 4.0:n teknologioiden tieteenalat. Tätä perspektiiviä käsittelevä tutkimusta ei tämän tutkielman aikaan olla tehty, ja sen myötä tämän tutkielman päätehtäviksi muodostui tutkia, miten standardisointi vaikuttaa Lean 4.0 -maturiteetin kehittämiseen, ja miten modernit standardisoinnin mahdollisuudet, erityisesti modernilla teknologialla integroitujen työkalujen kyvykkyydet, voisivat parantaa näitä vaikutuksia. Tutkimus toteutettiin tapaustutkimuksena analysoiden useita tiedonlähteitä: älykkääseen tuotantoon johtavaa Lean-transformaatiota läpikäyvän tapausyrityksen nykytila ja toimintasuunnitelma, Industry 4.0-integroidun Lean-standardisointityökalun ominaisuudet, kuvaileva tilastollinen analyysi ja korrelaatioanalyysi Lean-maturiteettia käsittelevästä kyselyaineistosta, sekä käsitellyn Lean-standardisointityökalun pilottitesti tapausyrityksessä. Tutkimuksen tulokset osoittivat, että standardisointi vaikuttaa Lean 4.0 -maturiteetin kehittämiseen toimimalla perustana perustavanlaatuisille operatiivisille muutoksille, yhtenäistämällä toimintatapoja ja siten tukemalla suorituskyvyn stabilisointia, minkä jälkeen se tukee operatiivisia parannuksia esikuva-analyysillä ja ylläpitämällä tehtyjä muutoksia. Käsiteltyyn Lean-standardisointityökaluun on integroitu useita Industry 4.0 -teknologioita standardisointiprosessin sujuvoittamiseksi ja sen visuaalisuuden sekä hyödyntämispaikalla esittämisen parantamiseksi. Nämä parannukset mahdollistavat yhteisöllisen osallistumisen standardisointitoimiin ja siten myös kehittävät organisaation siihen osallistumista, onnistumisten sekä haasteiden tunnustamista sekä ongelmanratkaisua, jotka kaikki ovat keskeisiä Lean-organisaatiokulttuurin periaatteita. Lisäksi käsitellyn Lean-standardisointityökalun Industry 4.0-integraatiot edistävät älykkään tuotannon teknologioiden asteittaista käyttöönottoa, kehittäen siten niihin liitännäistä tietoisuutta, kommunikaatiota sekä haasteiden diagnosointia. Keskeisenä liitännäisenä tekijänä todettiin myös johtajuuden ja riittävän koulutuksen korreloivan sekä onnistuneiden Lean-kehitysten että käsitellyn Lean-standardisointityökalun ja sen Industry 4.0 -ominaisuuksien onnistuneen käyttöönoton kanssa, toimien molemmissa tapauksissa muutosvastarinnan lieventäjänä. Kokonaisuutena tämän tutkielman tulokset suosittelevat Lean-painotteista Lean 4.0 -lähestymistapaa, jossa Lean ja sitä tukevat Industry 4.0 -teknologiat otetaan asteittain käyttöön ennen laajamittaisia älykkään tuotannon toteutuksia.

AVAINSANAT: Standardisointi, Lean, Lean 4.0, Industry 4.0, älykäs tuotanto, maturiteetti

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Abbreviations

2SL	2 second Lean
3S	Sort, shine, standardize
5S	Sort, systemize, shine, standardize, sustain
ABB IEC LV	ABB IEC Low voltage motors
AI	Artificial intelligence
CMMI	Capability Maturity Model Integration
CPS	Cyber-physical system
CSF	Critical success factor
ERP	Enterprise resource planning
G.R.E.A.T.	Gemba, recognized, easy, available at the point of use, tested & trained
HCPS	Human-cyber-physical system
HMI	Human-machine interaction
I4.0	Industry 4.0
I5.0	Industry 5.0
IMS	Integrated management system
ISO	International Organization for Standardization
JIT	Just-in-time
KPI	Key process indicator

L4.0	Lean 4.0
L5.0	Lean 5.0
LSS	Lean six sigma
MES	Manufacturing execution system
MM	Maturity model
PDCA	Plan-do-check-act
Q4.0	Quality 4.0
RQ	Research question
SOP	Standard operating procedure
SPC	Statistical process control
TPS	Toyota production system
WIP	Work-in-progress

1 Introduction

In strides made by companies to ensure both internal and external competitiveness, operational excellence plays a pivotal role. Excellence in this regard is considered as flawless and effective proficiency in an organization's processes, and is most often the result of successful strategic positioning driven by factors like cost-effectiveness, quality, flexibility and speed (Slack & Lewis, 2020, p. 17). These factors' competitive prioritization and the strategies implemented in their pursuit can vary greatly, for example through Porter's generic strategies, but general consensus in increasing revenue through internal operations management is to increase throughput, decrease excess inventory or cut operating costs (Goldratt & Cox, 2014).

As mentioned above, different types of strategic approaches have been developed in pursuit of competitive ability. Lean management is a distinguished operations strategy model, that emphasizes continuous improvement in value creation and organizational capabilities through elimination of operational waste (Modig & Åhlström, 2013, p. 117). Whereas the competition factors described by Slack & Lewis (Slack & Lewis, 2020, p. 17) are mainly reached in Lean-managed organizations by utilizing and altering already existent resources and capabilities (Modig & Åhlström, 2013, p. 71–74), another strategic approach emphasizes machinery modernization to improve process capabilities. The current state-of-the-art machinery and innovations are labelled in academic literature as smart manufacturing for their digitally cognitive and precise capabilities, and as components of Industry 4.0 (I4.0), the fourth industrial revolution (Pozzi et al., 2023, pp. 139–141). Lean and I4.0 emphasize different approaches to improving operations, yet the two are extensively researched in tandem under the term Lean 4.0 (L4.0), where wasteless operations are performed through digitally integrated smart manufacturing (Komkowski et al., 2025, p. 608). These studies highlight factors like the digitalization of traditionally physical components of Lean practices, joint implementation methods, effect analyses and much more.

1.1 Systematic development & key milestones: emphasis of this thesis

For both approaches, understanding the current stage or level of adaptation is often measured with maturity models (MM), which are measuring systems for any given form of operational definitiveness. The models most often comprise of measured key dimensions or general ordinal stages, each with their own criteria for value calculation or progressing onto the further levels. Utilizing MMs at the start of an operative transformation can systemize its process and give an organization a more precise state of itself, describing the sorts of actions optimal to be taken at each developmental stage. In such MMs and other development systems made for Lean transformations, standardization of work and developing standard operating procedures (SOP) are often described as vital factors to be implemented at the early stages.

The case company for this thesis, ABB IEC Motors Vaasa, is currently undergoing a Lean transformation leading to smart manufacturing in the future. At the time of this thesis, the initiative is in its early stages and is currently using SOPs as the main tool for commonizing operating procedures in preparation for improving them. Although often described as a vital factor in professional Lean literature, academic research regarding standardization is non-existent, especially regarding L4.0 transformations. By extension, neither modern SOP methods nor capabilities have any dedicated research. This thesis explores the current state-of-the-art developments of SOP capabilities, and how they are used in building L4.0 organizations.

1.2 Research questions, objectives and purposes

The purpose of this thesis is to explore L4.0 transformations through a systemized MM development, with SOPs as the main utility and perspective. In this pursuit, modern SOP innovations are examined and their impact assessed in context to traditional practice variants. In addition, these innovations' roles at every stage of an ordinal Lean maturity development are reviewed. These objectives are concentrated into two research questions (RQ):

- RQ1: How does standardization affect progressing in Lean 4.0 maturity?
- RQ2: How can modern opportunities improve these effects?

Through these objectives and RQs, an additional objective as requested by ABB IEC LV Motors Vaasa is to highlight the importance of a Lean transformation in transition to smart manufacturing, as well as that of modern counterparts to traditional Lean tools and techniques. A notable limitation of this research is in its use of a single case company, which therefor limits the valid generalization of its results.

2 Literature review

A broad literature review was conducted to illuminate the current context of research and common literature as described in the methodology. In addition to brief overviews of I4.0, Lean, and L4.0, critical matters in these subjects' regard are typical developmental progressions for the approaches, the role of SOPs in them, context to employee engagement and process ownership, typical critical success factors (CSF) and barriers of L4.0 transformations.

For examining development structures for Lean, I4.0 and L4.0, a plethora of MMs have been created for the approaches. These models can vary greatly in their application domains and purposes, systems of measurement and overall complexity. The most common MMs consist of 4-5 ordinal stages, which to be progressed in require the fulfilment of qualitative criteria, e.g. specific operating procedures or considerations (de Bruin et al., 2005, p. 2). For example, the International Organization for Standardization (ISO) (2018, p. 31–61) has specified a five-stage self-assessment model for operational maturity in their ISO9004 standard that integrates among other factors stakeholder inclusion, internal processes and organizational improvement. Another model for overall operations maturity is the Capability Maturity Model Integration (CMMI), sufficient ranking in of which is known to be used to determine suitable business partners in some business environments (Osiecki et al., 2011, p. 1).

The examples of ISO9001 and CMMI illuminate the diverse purposes of MMs, which can be for internal analysis, stakeholder expectations and more. Due to this, when inspecting L4.0 transformations from start to completion, analysis of only MMs is insufficient, as some are not purposed purely as instruments of such projects. Attention is to be brought to different forms of instruction as well, like roadmaps and other developmental progression systems. This analysis will also highlight the similarities and differences between maturity models and development systems.

2.1 Lean management

Since Lean fundamentals have been thoroughly examined in research and professional literature, this portion focuses only on aspects considered essential for reflection to the case company; affiliated Lean and its SOP practices, their effects and requirements on employee engagement and leadership inclusion, and their role in developing Lean maturity. In addition, an important highlight regarding suitable interplay between Lean and I4.0 in L4.0 through Lean philosophy implementation is examined to justify Lean emphasis in L4.0.

2.1.1 Relationship between Lean philosophy and methods in L4.0 context

Although Lean thinking has a plethora of positive effects to organizational performance, negative perceptions of the practices due to past experiences are common. Most Lean transformation initiative failures occur due to insufficient adoption of its philosophy and culture (Liker, 2004, p. 7–14; Modig & Åhlström, 2013, p. 92–94). This type of underperformance is often characterized by an overfocus on Lean tool adaptation without sufficient resource allocation to its CSFs and barriers, like employee training to said tools or the underlaying principles of why they are used (Chiarini & Brunetti, 2019, p. 1092). Thus, it is important to note that standard-centrism in L4.0 initiatives is not to solely implement standardized work but rather understand the Lean philosophy that most often deduces the method as a suitable approach.

Modig and Åhlström (2013, p. 140–146) project a four-stage Lean means abstraction model connecting Lean values, principles, methods and tools through levels of abstraction presented in figure 1. The model demonstrates that all decisions and activities in an organization are to be based on overarching values manifested as principles, which are pursued through methods utilizing their respectable tools and functions. Descending in the model decreases the level of abstraction and increases the connection between the goals and the means (Modig & Åhlström, 2013, p. 140–146). SOPs can from this perspective be seen as a method for eliminating variation and waste, performed with e.g. standardized work sheets or their innovations examined later in this thesis.

Regarding the innovations and their role in L4.0, the main delivery of the Modig and Åhlström model in context to smart manufacturing is its relationship with Lean: In L4.0 operations, I4.0 implementations are methods, tools & functions performed in accordance with Lean values and principles (Fani et al., 2024, p. 124; Komkowski et al., 2025, p. 608). For a hypothetical example, whereas utilizing the advanced capabilities of I4.0 big data analysis can be vital for data-centric operational systems, it remains an alternative method in an organizations pursuit of values like operational excellence and proof-based decision making. Considering smart manufacturing on a higher level in the model exposes the subject to a Lean barrier in the form of operative means overtaking their goals in importance, a common phenomenon in failed or underperforming Lean initiatives (Modig & Åhlström, 2013, p. 140–146). This perspective is also supported by the L4.0 implementation framework by Bueno et al. (2023, p. 8), which quotes Lean transformation before I4.0 implementations as a CSF. The study also enumerates other CSF for L4.0 implementations that are directly related to sufficient philosophical and cultural implementation of Lean, like system understanding, continuous learning programs, organizational learning, implementation acceptance and more (Bueno et al., 2023, p. 8).

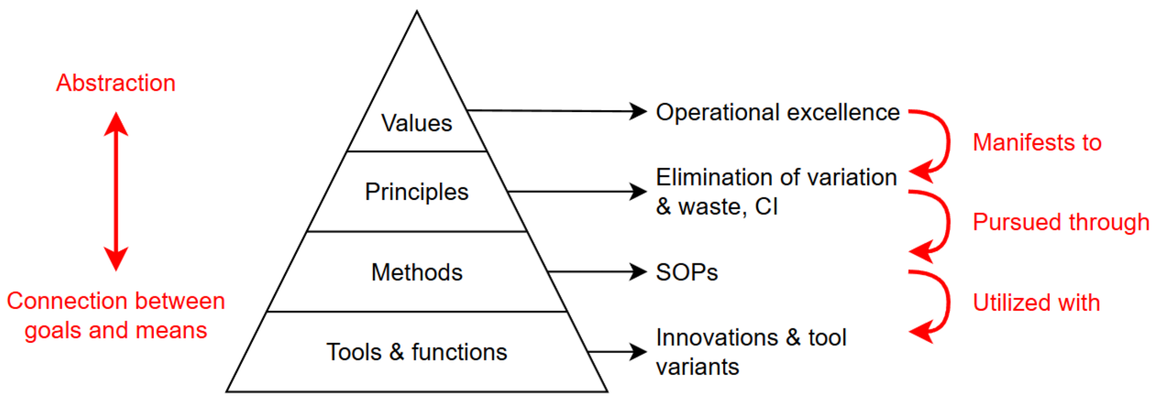


Figure 1. Lean means abstraction model (Modig & Åhlström, 2013, p. 140–146).

A similar hierarchy of means and methods is described by Liker & Meier (2006, p. 172–174). The main deliverable of their perspective is in the placement of business strategy between the principles and the methods: their figure has put the philosophy of waste elimination as its pinnacle, practiced by the principle of getting the quality right on the first time, which is then pursued through company strategy dictating suitable methods and tools. This perspective further enforces the lower role of smart manufacturing in such models, as strategic decisions, like operations planning and digital machinery acquisitions, should be done in accordance with an organization's principles and values, which should align with Lean philosophy in Lean-emphatic L4.0 organizations.

2.1.2 Lean standard operating procedures: employee engagement & benchmarking

The interpretation of Lean standardization by Liker & Meier (2006, p. 111–127), called standardized work, is the main perspective of such in this thesis. The objective of introducing standardized work into organizations is to commonize and stabilize its processes and by thus serve as the foundation for continuous improvement; as per Ohno (2013, p. 175), improvement without standardized work is significantly more difficult if not impossible. To serve as the foundation for continuous improvement, standardized work has multiple utilizations: it is used as an analysis tool for waste removal, dictates the basic method for process progression, is used in job instruction training to deliver the core value delivery from other forms of requirements and standards, promotes problem solving by the workforce, and much more. What differentiates Liker & Meier's standardized work from other forms of standardization is in its intended point of use being at the location of the documented event, and that it is based on external & internal requirements described in other forms of standardization, for example operations specifications defined on a management system level (Liker & Meier, 2006, p. 118–122).

As per Liker & Meier (2006, p. 126–131), standardized work charts are the main physical tool for standardized work. Figure 2 illustrates an example of what their definition of a SOP includes: basic elements shared with common standardization practices include brief listing of the crucial work steps, their intended durations, and cycle time. More characteristic qualities to Lean include Takt time specification, walking duration in the cycle time, and the flow diagram of the process. These additions are purposed to aid in waste identification and removal, enhanced visual management, designing operations to schedule according to external demand and minimize work-in-progress (WIP) levels (Liker & Meier, 2006, p. 126–127).

Example of a standardized work sheet

Job name		Part name:	T/L:	SIP stock:
Group		Part number:	G/L:	Takt Time: 90s

#	Work elements	Work time	Walk time
1	Action 1	10	1
2	Action 2	4	1
3	Action 3	15	2
4	Action 4	5	2
5	Action 5	2	1
6	Action 6	12	3
7	Action 7	3	1
8	Action 8	10	2
9	Action 9	5	
	Total	66	13

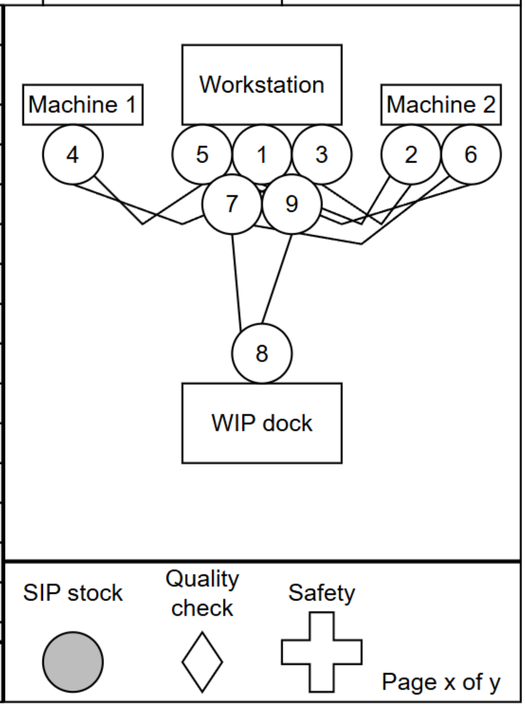


Figure 2. Standardized work sheet (Liker & Meier, 2006, p. 126–131).

A common component in Lean organizations is an active organizational culture fostering high levels of employee engagement. The pinnacle of the Lean philosophy as per Liker (2004, p. 13) is problem solving and its allocation to all employees of the organization, creating employee ownership of operations and processes. SOPs have a central role in this pursuit: standardized work sheets are to be prepared with assistance from the employees performing the processes, thus ensuring true understanding of the process deliverables, optimal way-of-working and a cultural pull-effect from the bottom upwards in the organization (Liker, 2004, p. 140–148). This role reinforces standard-centrism in Lean transformations as an enabler of cross-organizational contribution and indulging in Lean philosophy and culture, continuous improvement and other Lean methods, tools and functions.

2.1.2.1 Leadership and training as facilitators of workforce engagement and change acceptance

As per Lean & L4.0 developmental models (Bueno et al., 2023, p. 6–12; Santos Bento & Tontini, 2018, p. 981; Torkkola, 2018, p. 72–79), achieving heightened levels of employee engagement is achieved through active leadership, managerial support and adequate training. A study by Kalsum et al. (2024) explored the role of transformational leadership in changing organizational culture and alleviating resistance to change. Transformational leadership is a style of organizational directorship that emphasizes employee empowerment by motivating and inspiring the workforce, ideally resulting among other things in a more dynamic organizational culture, employee job commitment and satisfaction (Kalsum et al., 2024, p. 57–62). The study found significant correlation between organizations practicing transformational leadership and positive results in these metrics, justifying the method as effective in achieving flexible and innovative organizational culture (Kalsum et al., 2024, p. 62–66). In a similar perspective, the education and training of the workforce have proved to produce similarly positive results to change acceptance and employee engagement. Experimental research by Veloso-Besio et al. (2019, p. 258–260) found statistically significant improvements in work motivation and organizational climate amidst organizational change in groups whose supervisors were subjected to training regarding change management, whereas groups without training saw decreased values. The impact of the training was explained as due to the developed understanding of positive psychology and social skills in the trained supervisors, which resulted in among other factors employee encouragement, positive feedback and overall greater employee wellbeing (Veloso-Besio et al., 2019, p. 258–262).

Active and empowering leadership is often considered an essential element in driving not only any type of organizational change, but especially Lean transformations. The same form of managerial contribution has also been noted as crucial in I4.0 implementations, where transforming machinery, entire processes, and by them the organizational culture can be prone to resistance to change by the workforce (Sarker & Dunston, 2025, p. 212–214). This similarity is also discussed in L4.0 research, where engaging leadership and workforce empowerment are considered essential barriers and CSFs. In their L4.0 implementation framework, Bueno et al. (2023, p. 8) identified cultural change in managerial practices, learning and knowledge management, and employee acceptance as CSFs, and insufficient workers' training support as a typical barrier. A high involvement of workforce in decision-making of their own processes is also often quoted as a necessity (Liker & Meier, 2006, p. 123–124). Similar CSFs and barriers are quoted in addition to L4.0 in both separate fields, highlighting that overcoming them in pursuit of one significantly assists in the implementation of the other. In context to implementing Lean standardized work SOPs, developing its acceptance in the workforce starts from the management and leadership efforts: from the management stage, initiating and formalizing adoption and allocating sufficient resources are crucial, transformational leadership creates a dynamic culture of its acceptance, and training creates understanding of its use which prevents resistance.

2.1.2.2 Employee SOP inclusion in ISO-certified systems: bureaucracy and autonomy

Employee engagement in SOPs is crucial to achieve their commitment to the practices and eventually continuous improvement. Without thorough inclusion and training at early stages of adoption, externally imposed standardization can be experienced as coercive bureaucracy by the workforce and thus result in low commitment and resistance to change. In contrast, including the workforce in the process of creating their SOPs can create engagement, sense of process ownership and decreased experienced coercion.

An important aspect in modern manufacturing environments often seen as a retarder or a barrier to employee SOP inclusion is ISO standardization. ISO standards are used as frameworks for systemisation of organizations' structures and processes, and certifications of qualification are often expected of reliable business partners (DNV, n.d.). Auditing to gain these certifications is performed examining the management system documentation of the candidate organization, which as per ISO9001 specifications requires adequate ownership, editing & approval systems (International Organization for Standardization, 2015, p. 8–9). These systems are purposed to ensure appointed responsibility and systematic upkeep of the management system documentation but are in addition often perceived as a source of tardiness in improvement initiatives, moreover a barrier to communally upkept instructions.

Due to these perceptions management system documentation as per the ISO-required format can often be the only form of officially recognized process instructions and standards in an organization, an example of which is illustrated in figure 3. The contents of process-instructive management system documentation are dictated by external and external requirements, like ISO9001 requirements, product specifications or stakeholder expectations, and comprises of how they are to be fulfilled. Liker and Meier (2006, p. 118–122) differentiate Lean standardized work from other types of standards, e.g. work & process standards, which are often prepared as per ISO requirements. Situations in which management system documentation is the only form of recognized and upkept instructions the contribution of the workforce in continuous improvement is minimal, since making improvements to the work and its documentation is a slow and bureaucratic process detached from its operators (Liker, 2004, p. 147–148).

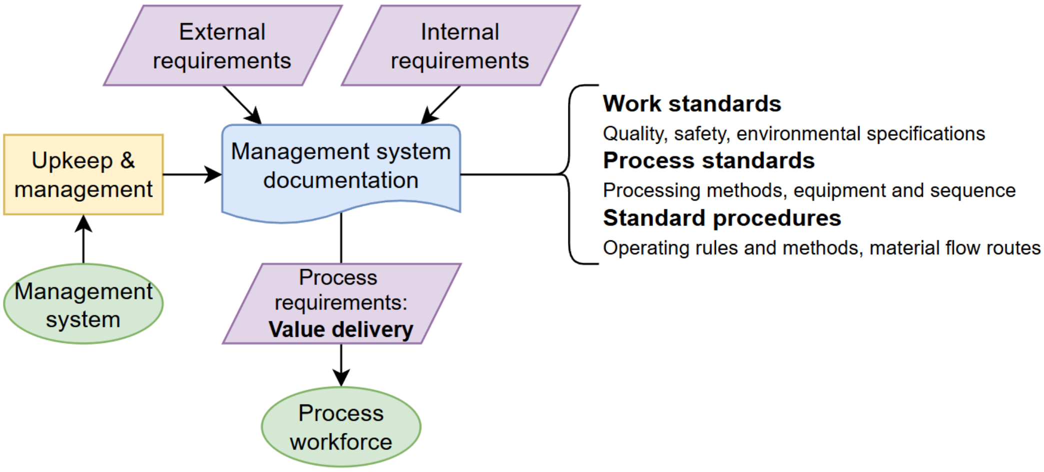


Figure 3. Typical ISO-required standardization as the only form of official instructions (International Organization for Standardization, 2015, p. 8–9; Liker, 2004, p. 147–148; Liker & Meier, 2006, p. 118–122).

In order to include the workforce to continuous improvement practices whilst not undermining ISO requirements, the differentiation of different types of standards' roles described by Liker and Meier (2006, p. 118–122) is crucial. A common myth about Lean workforce standard ownership concerns the level of independence in the standardization process, which according to Liker and Meier (2006, p. 123–124) should only include controlled autonomy after initial SOP creation. Liker (2004, p. 145) argues that bureaucracy is not necessarily a negative trait in the technical structures of organizations, but rather that employee empowerment is enabled through their social structure. Whereas coercive bureaucracies use strict hierarchical control and can cause negative cultural implications, enabling bureaucracies use their hierarchies, procedures and standardization as enabling systems for employees to utilize and aid them in contributing to continuous improvement (Liker, 2004, p. 145–148). In such systems, the employee SOP contribution comes in the form of improving their standards prepared by an appropriate party in the management system, consisting of only the core deliverables of the described process to allow for performant flexibility. In addition, the improvements that the workforce makes to the standards are to be governed by the management system to ensure that the value delivery or actual measurable improvement are not compromised (Liker, 2004, p. 143–148). This level of governance enables employee contribution and enables adequate upkeep procedures required by ISO specifications, illustrated in figure 4.

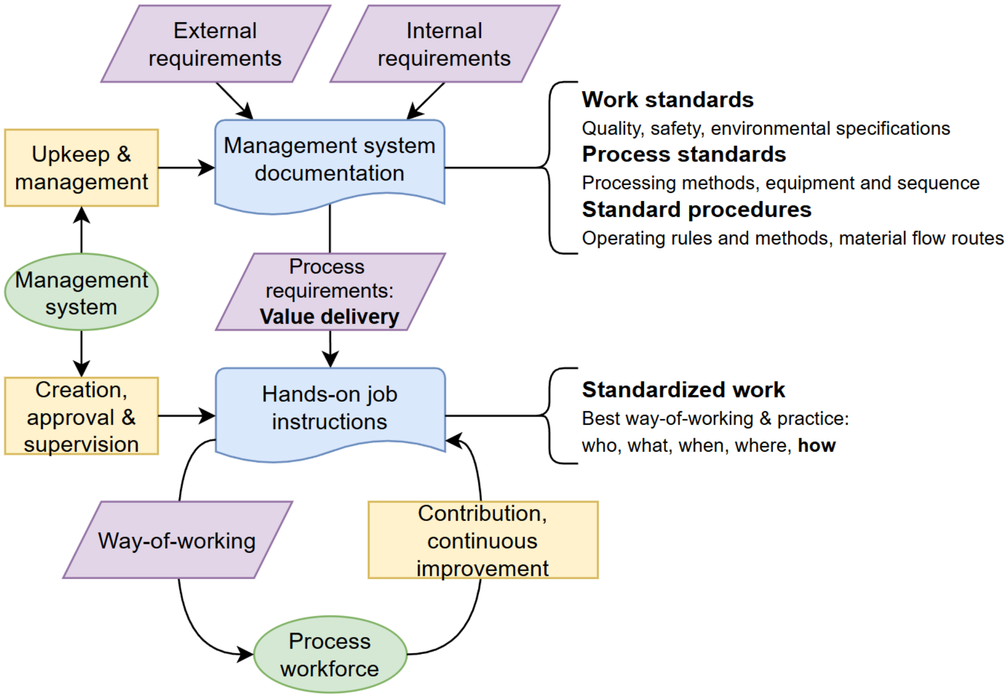


Figure 4. Lean standardization and employee contribution in ISO-required systems (Liker, 2004, p. 143–148; Liker & Meier, 2006, p. 118–124).

2.1.2.3 Counterargument of necessity: factorial subjectivity

Whereas the concepts of employee empowerment and autonomy are considered tenets in traditional Lean literature, their essentiality have been questioned in research. For example, Chiarini and Brunetti (2019, p. 1096-1098) interviewed Lean organization managers in mapping essential Lean CSFs, and a notable amount of respondents dismissed the necessity of employee empowerment and autonomy. In testing which hypothesized CSFs bear evident necessity in Lean organizations, other dismissed factors included written procedures and standards, ISO9001-accordant management systems, and financial sustainability of Lean projects (Chiarini & Brunetti, 2019, p. 1096–1098).

It is important to note the subject-dependence of these dismissed factors. For example, like described above, ISO9001-certification can be an uncompromisable factor in many global business environments, and written procedures and standards are crucial in achieving it. Much of what can be considered as necessary in business organizations is directly influenced by their internal and external requirements, as well as their current and ideal operational states. In development of the current state to the ideal one, the roles of the factors are to be borne in mind through the abstraction-hierarchical relationship between goals and means as per Modig and Åhlström (2013, p. 140–146): Whereas the ISO framework may not be an essential aid in Lean transformations, both ISO certification and Lean management should be considered as means in pursuit of operational excellence, rather than goals.

Some of the dismissed factors are already addressed as non-essential in different forms of classic Lean literature. The dismissal of employee autonomy can have to do with the accordant myth described by Liker and Meier: the interview respondents of the Chiarini and Brunetti (2019, p. 1098) research who dismissed employee autonomy reasoned that all Lean initiatives need to be based on and evidently improve the organizations' goals. This description bears similarity to the arguments made by Liker and Meyer, as in enabling bureaucracies sustaining a level of management to ensure actual progress in continuous improvement. Overlooking short-term financial gains is also addressed by Liker (2004, p. 69–73) as a tenet in Lean philosophy, as all decisions are to be based on long-term philosophy, even at the cost of short-term financial performance. As for the SOP perspective to requirements subjectivity, workforce inclusion in the process not only seeks to uphold problem-solving organizational culture, but also to ensure thorough understanding of the process deliverables and the best way-of-working as a central Lean principle "genchi genbutsu", translated to "go and look" (Liker, 2004, p. 223–225).

2.1.3 2 Second Lean: culture-centrism, contrasts to other approaches

In relation to the importance of employee engagement and acceptance as a Lean CSF, an important highlight of modern Lean practices in the context of the case company of this thesis is 2 Second Lean (2SL). Considered to have established in 2011 by Paul Akers, 2SL is an approach to Lean that emphasizes the creation of an intensive organizational culture which drives daily incremental contributions to continuous improvement from all members of an organization, as per the name of the approach by saving 2 seconds of operative time each day (Akers, 2021, p. 60–64). This expectation set to the employees reinforces organizational learning and problem solving, which are considered CSFs of Lean implementations (Bueno et al., 2023, p. 8).

To enable high levels of participation in such organizational culture, another emphasis of the 2SL approach is to simplify Lean practices and make them easier for anyone in the organization to contribute to: for example, the work environment upkeep method of 5S, which stands for sort, set in order, shine standardize, and sustain, is simplified to 3S, sort, sweep, and standardize (Akers, 2021, p. 42–48). In the perspective of SOPs, the acronym G.R.E.A.T. by Hughes (2023, p. 21–32) describes how effective documentation of a process can enhance performance from workforce inclusion, and according to it an effective process and its standardization is;

1. G – Gemba, i.e. documented and performed with deep understanding of the object in question.
2. R – Recognized, i.e. recognized as their own and important by the people performing the object in question.
3. E – Easy, i.e. fluent and easy to utilize, create and modify.
4. A – Available at the point of use, for example SOP is found and possible to utilize at the object in question.
5. T – Tested & trained, i.e. compiled according to best known practice and tested before implementation.

The steps of the G.R.E.A.T. acronym shape Lean standardization to a simpler and more approachable form when compared to the version by Liker & Meier (2006, p. 127), and by thus further enable communal contribution. The L4.0 SOP innovations discussed in this thesis are designed as per this philosophy and elaborated upon in the results section. 2SL has many contrasts to other Lean approaches. Most notable differences are with Lean Six Sigma (LSS), which utilizes statistical process control (SPC) to eliminate variation, and the main source of continuous improvement comes from define-measure-analyse-improve-control (DMAIC) initiative cycles that are based on current and desired future KPI levels (Torkkola, 2018, pp. 74–76). The approach is thus inherently data-centric and highly statistical by nature. In contrast, 2SL literature discourages KPI overdependence, emphasizing the pull-effect from the Lean culture to drive performance improvement (Hughes, 2022, p. 19–20). Despite this difference in methods, it is important to note that much of the reasoning behind them is shared; the methods of waste and variation elimination are in both approaches derived from Lean values and principles like pure value delivery, levelled production, and waste elimination (Akers, 2021, p. 38–89; Oakland et al., 2020, p. 291). This relationship between LSS and 2SL is displayed in Figure 5, in which the shared values of the approaches further demonstrate the importance of Lean philosophy integration beyond basic methods and practices.

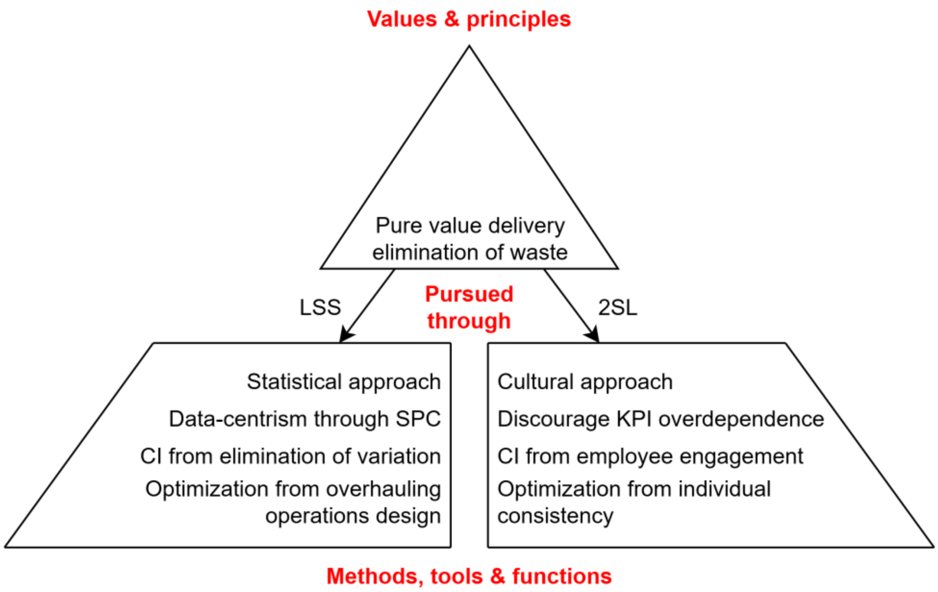


Figure 5. derivation of Lean philosophy to practices in LSS & 2SL (Akers, 2021, p. 38–89; Oakland et al., 2020, p. 291; Torkkola, 2018, p. 74–76).

2.1.4 Developing Lean: highlight on the Torkkola steps for improvement

Lean MMs follow uniform developments compared to each other more often than their I4.0 counterparts. This can be due to the higher maturity of the Lean application domain, which has been developing in the global context since Womack, Jones & Roos published The Machine that Changed the World in 1990, which is often considered the first essential work in western Lean literature. Studies of I4.0 have mostly popularized in the last 15 years (Muhuri et al., 2019, p. 220), demonstrating a significantly less mature application domain. In addition to the more mature field of study, the application purposes, methods and expected outcomes of Lean MMs are more uniform than that of I4.0 implementations, or are defined on a higher level of abstraction as per Modig & Åhlström (2013, p. 140–146).

The similarity of Lean development models is best visualized through the Torkkola's (2018, p. 72–78) steps for improvement, which despite being a form of roadmap by nature, also shares many qualities with ISO-inspired Lean MMs. The objective of the model is to describe the main phases of an organization from the initial stage to optimization with an emphasis on process stabilization (Torkkola, 2018, p. 72). The model's four stages are as follows:

1. The chaotic stage. The initial setting when starting a Lean transformation is characterized by unpredictable process performance through excessive variation. Progressing from this stage requires process standardization and measurement, as well as staff education.
2. The organized stage. The organization has attained common operating methods through process standardization, but significant performance disturbances called special causes still induce variation to the performance level. Progressing from this stage requires in some cases statistical process control (SPC) and an organized method for solving special causes.
3. The stabilized stage. After solving the most significant special causes the process performance levels have become stable and predictable, and variations can only be considered random. Progression to the final stage of the model starts the optimization of processes, redesigning the operative system as per Lean operating procedures, e.g. LSS or Just-In-Time (JIT) management.

4. The optimized stage. At the final stage processes are stable and optimized, and their performance levels are evaluated on external demand.

It can be observed that most of the stages focus on eliminating variation in processes and stabilizing them. The stabilization efforts begin with process standardization, which is considered the basis of continuous improvement (Ohno, 2013, p. 175). The use of SOPs commonizes operating procedures and thus reduces the most critical variation, after which improvements are made onto this newly documented base level. Correspondently updating and sustaining these SOPs prevents the fall-back of the newly achieved performance level, which without process standardization is a significant risk (Liker & Meier, 2006, p. 112).

For comparison to the development of the Torkkola model, Dos Santos Bento & Tontini (2018, p. 981) have presented a Lean maturity model based on ISO specifications. Whereas the model does not list necessary steps for progression but rather only ascencion criteria, their corresponding stages are as follows:

1. [Lean] not implemented or implemented informally. The initial setting, which is characterized by unstable performance results.
2. [Lean] formally implemented. At this stage the implementation is officially recognized and initialized, and its deployment is scheduled.
3. [Lean] deployed & documented with occasional failures. The implementation has been started, but displays flaws in the operational performance.
4. Indicators under control. The flaws from the last stage have gotten solved, process indicators have been solved and planned results are starting to get achieved.
5. Controlled & constantly improving. The processes are now under control and predictable, and the organization has seen continuous improvement over the last 12 months.

The similarities of the Torkkola and Dos Santos Bento & Tontini models are visualized in figure 6. As can be observed, the two models share significant similarities: the initial settings display unpredictable and unstable results with abundant variation. After the beginning of the implementation, significant flaws induced by special causes can still be observed. Before starting fundamental improvement efforts the processes are stabilized, and the pinnacle of implementation is a continuously improving and optimized system. Although not mentioned particularly in the Dos Santos Bento & Tontini model, it can be understood through this similarity that process standardization has a substantial role in developing mature Lean systems, as a stabilizing factor in preparation for fundamental changes; the operational chaos in initiality is corrected through commonizing activities with standardization, major deviations from set operating levels are compared to the standard and by thus prevented in updating the SOPs, which when eliminated grant the operations predictable stability.

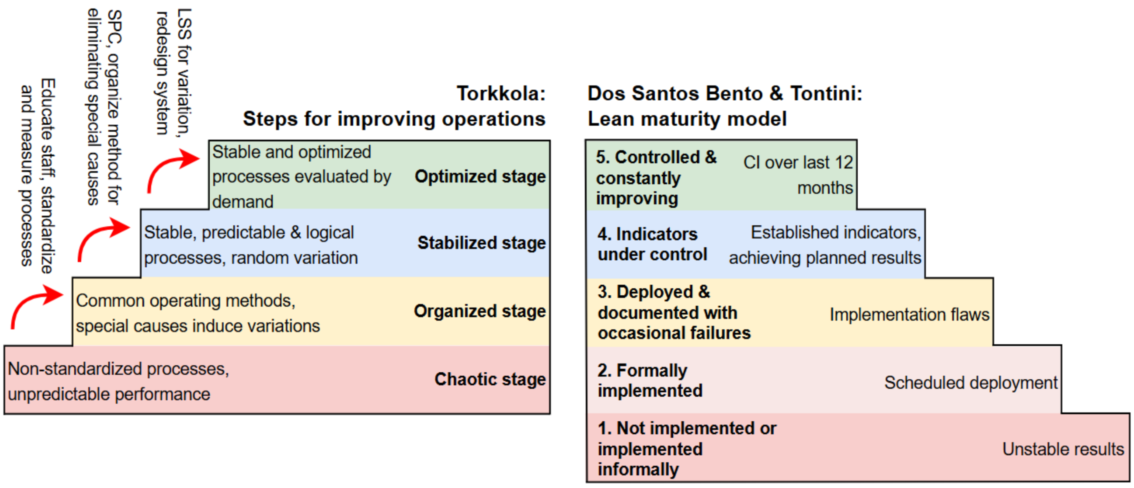


Figure 6. Lean development models (Santos Bento & Tontini, 2018, p. 981; Torkkola, 2018, p. 72–78).

2.2 I4.0, smart manufacturing

Modern innovations in manufacturing are labelled as technologies of the fourth industrial revolution (Muhuri et al., 2019, p. 218–219). The base of the fourth industrial revolution is often seen as the emergence of digitalization in modern manufacturing technology, and most of the I4.0 technologies resonate this basis; a literature review by Suleiman et al. (2022, p. 18–21) found that by 2022, 80% of presence intensity in academic I4.0 literature concerned the technology groups of smart sensors and actuators, big data analytics and simulation, additive manufacturing, enterprise systems, cyber-physical systems (CPS) and cloud technologies, all of which are in some form digitally integrated. Another aspect of I4.0 technologies is their use in quality management, which is labelled quality 4.0 (Q4.0) in academic literature. Although affiliated with quality management, research concerning I4.0 or Q4.0 implementations to SOP management is non-existent.

Digital integrations through I4.0 technologies have proven to be impactful operative approaches. A study by Arcidiacono & Schupp (2024, p. 470-472) found statistically significant correlation between smart manufacturing adoption and its impact on operational dimensions like cost, quality and delivery. However, little correlation between impacts on operational performance and financial performance was found in smart manufacturing adaptations, which according to Arcidiacono & Schupp could signal of differences in strategic reasoning of I4.0 implementations; some industries may pursue smart manufacturing only to maintain market position in a growingly competitive business environments (Arcidiacono & Schupp, 2024, p. 473). Such environments pursuing I4.0 implementation signal not only of the benefits associated, but also of possible strategic necessity.

2.2.1 I4.0 development: model diversity, focus in general smart manufacturing

Like mentioned above, I4.0 MMs and development frameworks are developed with greater variation of application objectives, subjects and overall purpose of the models themselves. Some models, like that of Sjödin et al. (2018), display the integration level of I4.0-affiliated technology in an industrial environment, whereas others target specific process portions, like the Bradley model that focuses specifically on organizational IT capabilities (Treviño-Elizondo et al., 2023, p. 12). Such examples further reinforce the placement of I4.0 implementations generally lower in the Modig & Åhlström (2013, p. 140–146) means abstraction model compared to what is recommended with Lean practices; the level of abstraction in I4.0 models is at large part lower and more objectively described than that of Lean models, which require more subject-focused and fitted implementation of philosophy defined in literacy with higher abstraction.

For the context of L4.0 transformations, the focus of this portion of the literature review was placed on MMs and development structures regarding general smart manufacturing implementations, with multiple technology group adaptations. Treviño-Elizondo et al. (2023, p. 11–12) found 14 maturity- and readiness models regarding I4.0 and smart manufacturing implementations, and a common factor within multi-technology-group models is the consideration of maturity based on multiple dimensions; people, processes, technology, resources etc. This is a contrast in focus to typical Lean MMs, which although incorporate them, follow more linear progressions in resemblance to roadmap methodologies ((Santos Bento & Tontini, 2018, p. 981; Torkkola, 2018, p. 72–78)).

Two examples of such models were chosen for examination. The first preliminary MM for leveraging digitalization in manufacturing by Sjödin et al. (2018, p. 25–29) incorporates the three main dimensions of people, processes and technologies, and builds their four-level model in acknowledgement of typical I4.0 implementation barriers in these dimensions and their suggested solutions. The model progresses as follows:

1. Connected technologies. This level prepares the people by creating an implementation-positive organizational culture through development inclusion and digitalization-competent recruitment, the processes by formally defining the implementation process and systemizing the inclusion of external parties in the transformation, and the technology by mapping current and new technologies while digitally connecting their applications for data flow improvement.
2. Structured data gathering and sharing. This level elaborates on the people by training them in connected data systems and restructuring roles to match proactive digital connectivity, the processes by creating data insight analysis processes

and building knowledge-sharing networks, and the technology by increasing data collection accuracy and automating data mining and sharing.

3. Real-time process analytics and optimization. This level further builds on the people by organizing sense-making events and recruiting data-analysts and scientists for further operations optimization, the processes by utilizing the insight analysis for operations optimization and creating evaluation processes to assess such efforts, and the technology by implementing real-time performance analysis systems as well as simulation systems of the digital factory or digital twin system to test and prototype its optimization.
4. Smart, predictable manufacturing. The last level achieves peak smart manufacturing maturity in the people by creating a culture of continuous I4.0 innovation as well as roles and responsibilities orientated into production predictability, the processes by creating data visualization processes for decision making as well as proactive processes for future production planning and forecasting, and the technology by creating monitoring and visualization systems for critical operations analytics and digital systems integration with external business partners for supply chain predictability.

Another perspective to highlight the variety of models in smart manufacturing is the multidimensionally measured MM by Schumacher et al. (2016). The model highlights a different approach to the use of different dimensions, where they serve as individual and hierarchical metrics to be improved in, rather than push for a unified transformation like in that of the Sjödin et al. (2018) model. The reason for this format is to assess the dimensions of which an organization lacks in preparation for smart manufacturing implementations; an example case company measured by Schumacher et al. (2016, p. 165) had a relatively low value in the I4.0 strategy implementation dimension, which with the help of the hierarchically structured dimensions was able to be specified to be due to a lack of an I4.0 roadmap utilization as well as communication and documentation of I4.0 activities. This example is shown in figure 7, which visualizes the strengths and deficiencies of I4.0 maturity through different dimensions.

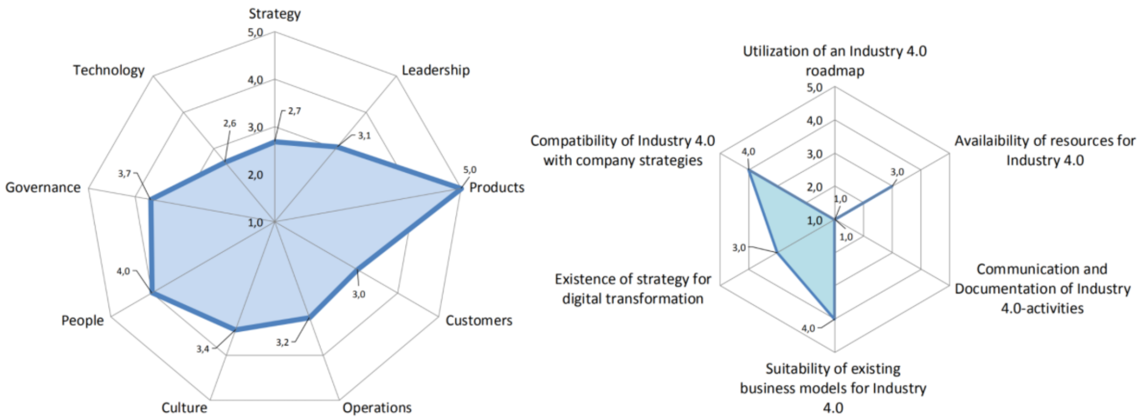


Figure 7. Multidimensional & hierarchical I4.0 maturity measurements (Schumacher, Erol & Sinh, 2018, p. 165).

Many notations can be made from the presented MMs. Firstly, building upon smart manufacturing maturity is technology-wise highly dependent on building digital operations integration and advanced data analysis. Despite this dependency and like noted also by Bueno et al. (2023, pp. 8–9), transforming operations into smart manufacturing requires organization-wide efforts in nearly all aspects of its structure and activities: strategy inclusion, leadership engagement, enabling culture and much more. These requirements also highlight the significant synergy and similarities to developing smart manufacturing and organizational Lean philosophy and practices, as all examples noted above are essential also in Lean transformations.

2.3 Lean 4.0

Combining I4.0 and Lean in a joint implementation is considered L4.0 in current research (Dillinger et al., 2022, p. 202). Whereas joint implementations also signify adopting both I4.0 and Lean as normal, L4.0 research has also sought to merge them with each other. Two main points of such can be observed: firstly, practicing smart manufacturing in accordance with Lean philosophy and methods. Although I4.0 capabilities like digital twin systems and advanced data analytics offer great potential in operations improvement, Lean practices can further elevate their impact: L4.0 research also examines the digitalization of Lean practices, with examples of digitized Lean methods including just-in-time scheduling with CPSs, single-minute exchange of die with additive manufacturing, and horizontally & vertically integrated Heijunka (Dillinger et al., 2022, p. 205).

Although this literature review has emphasized an approach of Lean priority in L4.0, other prioritization has also been researched: main perspectives of L4.0 application are implementing I4.0 as an emphasis, Lean as an emphasis, and a balanced implementation (Komkowski et al., 2025, p. 608–609). The I4.0-dominant perspective prioritizes the leveraging impact of smart manufacturing in overcoming Lean limitations, and by thus demonstrate lesser adaptation of Lean philosophy in preference of only digitizing common operating methods, for example electronic kanban signalling systems (Komkowski et al., 2025, p. 608). Such examples consider Lean lower in the Modig & Åhlström (2013, p. 140–146) means abstraction model, at the level of methods or tools and functions. Balanced implementations also utilize I4.0 leverage for performance development, but in addition incorporate Lean culture and values further into the organizations (Komkowski et al., 2025, p. 609).

Despite these alternative perspectives, Lean emphasis remains as a priority in this literature review, for not only the hierarchical settings of the Modig & Åhlström (2013, p. 140–146) means abstraction model, but also the perceived benefits of full philosophical integration of Lean into organizational culture. Komkowski et al. (2025, p. 608) list implementation-technical benefits of the Lean-dominant approach, which include the simplification of the I4.0 integration process, prevention of digitally transforming wasteful activities, achievement of CSFs, improvements in dynamic capabilities and more. In addition, the mentioned benefits of digitalizing Lean methods are to be noted. Dillinger et al. (2022, p. 205–206) found strong effects by I4.0-integrated Lean methods in operational key dimensions like time, cost and flexibility, with technologies like value stream mapping with CPSs and simulations, single-minute exchange of die with additive manufacturing, Jidoka with intelligent objects and actuators and sensors and many more.

2.3.1 Developing Lean 4.0: Lean emphasis

Developmental model research in the L4.0 field is scarce and not directly linked to the mentioned Lean or I4.0 emphases in joint implementations. However, both models examined in this thesis can be perceived to focus on balanced implementation, as neither approach is necessitated as a prerequisite in the initial settings of the models.

The first development model is the Lean 4.0 implementation framework by Bueno et al. (2023). The progressional approach of the framework is a cyclical four-step implementation plan to gradually integrate both Lean and I4.0 elements through continuous improvement. The cycle is designed per the PDCA cycle, and circulates as follows:

1. Plan, system analysis and problem identification. By analysing the application environment, the chosen problem or issue is defined and objectives to its solution are formulated. Possible associated Lean-I4.0 synergy elements are assessed, which Bueno et al. (2023, p. 7–10) define as Lean practices performed with I4.0 technologies. These possibilities are assessed for suitable utility in context of the objectives, and by identifying possible barriers and CSFs affecting them a plan of implementation is formulated and started.
2. Do, perform the planned implementation. Important activities include understanding the criteria for objective completion, delivering the organizational change, educating the workforce, and managing vital resources like time and budget.
3. Check, observe the impact in relation to the objectives. Results checking includes the acquired benefits, completion of integration set points, necessary adjustments, and more. Benefits can be labelled into four main categories: operational performance, financial performance, safety, and people.
4. Act, completing necessary adjustments and continuous improvement. Changes necessitated in the last step are done, and continuous improvement is to be maintained through the documentation and implementation of best practices.

Although the implementation plan can be utilized without prior experience of neither Lean nor I4.0, Lean is noted as a CSF to be considered in the first step. This issue could be solved by introducing a MM to follow overarching development and utilizing this implementation plan as an integration tool within it. Such development could be accomplished with the L4.0 MM by Treviño-Elizondo et al. (2023, p. 13-18), which seeks development from three perspective dimensions; “smart” processes, “smart” people, and “smart” products. These dimensions are assessed from the perspective of the strategic pillars of Lean and I4.0, which guide the maturity levels as follows:

1. Identify Lean value, create or raise I4.0 diagnostic / awareness. Development in processes happens through analysing and identifying operational value, in people through communication of I4.0 challenges and systems design to fill skill gaps, and in products through thorough understanding of customer needs and expectations.
2. Map Lean value stream, Plan and educate I4.0 approach. Development in processes happens through inter-process connections and further standardization, in people through creating training programs to fill mentioned skill gaps, and in products through indirectly acquiring product information of user habits.
3. Create Lean flow, initiate I4.0 adoption / pilotage. Development in processes happens through automating decision making and raising business intelligence, in people through endorsing I4.0 practices and utilizing its technologies in data analytics and decision making, and in products through developing the products to generate direct information of user habits.
4. Establish Lean pull, scalability in the I4.0 domain. Development in processes happens through digitally interconnecting processes horizontally and vertically, in people through fostering change-driving teams and establishing I4.0 policies, and in products through developing them to be able to share information with other smart products.
5. Seek Lean perfection, I4.0 leadership / ecosystem. Development in processes happens through process innovation achieving flexibility and scheduling capacity per external demand, in people through sharing best practices with supply chain

partners and stakeholders, and in products through developing them to proactively seek smart product connections for information sharing and autonomy.

To connect this MM to the possible role of standardization included, the Lean strategic pillar in the Treviño-Elizondo et al. (2023) MM is based on the Womack & Jones (1996, p. 1-2) principles of Lean thinking; specify value, identify the value stream, flow, pull, and pursue perfection. The role of Lean standardization resonates through this connection in a similar way to that of the Torkkola (2018, p. 72–78) steps for improving operations; the value of activities is identified and documented in process standardization to stabilize operations, after which fundamental changes, like creating Lean flow and pull, are performed. With all I4.0, Lean and L4.0 development models now examined, another connecting factor can be seen as crucial: workforce education and commitment. Like how standardization contributes to the stabilization of the first levels in both the Treviño-Elizondo et al. (2023, p. 13–18) and the Torkkola (2018, p. 72–78) models, they also take notation of identifying deficiencies in employee capacity and skillset.

2.3.2 I5.0 & L5.0: human-machinery coexistence, 2SL synergy

Lean literature often dismisses excessive automation and mechanization of processes as a suitable developmental approach from the perspective presented here through the Modig & Åhlström (2013, p. 140–146) means abstraction model, distinguishing them from organizational goals rather as their means. In addition, this dismissal warns against overdependence to machinery, a perspective of which Ohno (1988) makes several notations of:

- Autonomation, also known as Jidoka or automation with a human touch, is preferrable over independent automated machinery. Autonomated processes change the roles of workers from machinery operators to its supervisors, allowing for process-tied workforce reductions and job rotations instead of its complete eradication (Ohno, 1988, pp. 5–7). The obsolescence of this perspective in context of modern machinery is important to note, but the emphasis of people-centrism remains relevant as is to be described below.

- Excessive information input and machinery overdependence can cause disruptions and confusion in production scheduling and cost increases; digital resources are not to be overlooked but utilized with caution (Ohno, 1988, p. 47–48).
- In pursuit of cost reduction, work improvements, as in changes to the way-of-working, should be done first and account for most of the reduction, only after which equipment improvements should be assessed. Reversing this order and prioritization creates minimal if not negative savings (Ohno, 1988, p. 67).

To elaborate on this perspective, the evolution of some I4.0 technologies, like artificial intelligence (AI) and its use in organizations, has created conversation of the changing if not endangered roles of people in value chains (Choi & Leigh, 2024, p. 1). As a response, the European commission has initialized a research field of enforcing the human role in developing industrial environments; whereas the here discussed technologies are considered as part of the fourth industrial revolution, the research regarding the fifth industrial revolution (I5.0) focuses on organizational human-centrism and the human-machine interaction (HMI) between them and the workforce (Peruzzini et al., 2024, p. 1426–1434).

2.3.2.1 Human-machine collaborative systems design in I5.0

A central motivation of I5.0 is the change in worker roles that the current technologies induce. To assess this change, I5.0 research seeks to create systems of symbiosis between the workforce and the technology, systematically integrating the people to the smart manufacturing systems. For example, Peruzzini et al. (2024, p. 1434–1438) propose a smart manufacturing system design framework for Industry 5.0 integrations, where information sharing and mutual evolution for human-automation symbiosis is facilitated through data sharing across four layered domains operated either by people or I4.0 technologies, which progress like follows:

1. Observable manufacturing domain. The physical layer of the system, the manufacturing environment, consists of the workforce, the machinery, and the HMI interfaces, all of which transmit data to the above layers into CPSs and human-cyber-physical systems (HCPS). I4.0 technologies in this domain include personal smart devices equipped by people, advanced censors in the machinery and the HMI tools connections to the CPSs and HCPSs.
2. Communication domain. The first layer of this domain, the communication layer, intakes the data from the below layer and performs necessary data management. The second layer of the domain, the information layer, then processes the received data for necessary information management for key information extraction. I4.0 technologies in this domain include advanced data analysis for the physical layer data, and the internet of things for key information extraction.
3. Digital twin domain. The first layer of this domain, the modelling layer, digitally shapes as artifacts in its knowledge model the products, the people, the machinery, the tasks and the HMI adaptations. The second layer, the digital simulation layer, places these models into a virtual environment in an augmented digital twin system to simulate said entities and tasks, mapping data from the HMIs. I4.0 technologies in this domain focus on the augmented twin systems.
4. User domain. The only layer of this domain, the AI-driven layer, takes all key information and data from the previous domains' layers and produce

Frameworks like this give clear directive to the roles that the workforce have in relation to the developing technology, and by so enable mutual development of both. An important development in relation to the explored I4.0 literacy is the cohesive application of most of the major I4.0 technologies into a unified system, while simultaneously designing it to support human presence and development.

2.3.2.2 2SL connections: L5.0

In a similar perspective of human effort prioritization, 2SL was examined as a culture- and people-centric, and technology overdependence-dismissive approach to implementing Lean, which due to its inherent human-centrism can be perceived as an efficient driver of I5.0 values. The dimension of Lean 5.0 (L5.0) has also popularized alongside I4.0, L4.0, and I5.0 in recent research, with the key difference of consisting not only of Lean and I4.0, but also the mentioned human centricity (Fani et al., 2024, p. 125-132).

Regarding the Lean or I4.0 emphases discussed in L4.0 approaches, L5.0 can be perceived as being a Lean-centric field of research; in pursuit of human centricity, Lean implementations do not limit to only basic operating methods, but also the intangible principles like workforce engagement and empowerment, continuous improvement and more (Fani et al., 2024, p. 125–127). In this pursuit, 2SL appears as a suitable approach, since it emphasizes organizational culture and individual development, achieving continuous improvement with the emphasis on individual people and their engagement.

2.4 Conclusion of the literature review

To conclude the literature review, standardization is perceived as a fundamental to operational performance improvements through multiple factors. Firstly, it serves as a point of reference for the documented object's value deliverance, adherence to which commonizes activities of the workforce, therefor reducing variation and stabilizing performance. Secondly, this reference point describes the current state of the object, which enables the planning of its ideal state and the actions to achieve such. Thirdly, in progression to this ideal state, the updated reference point prevents fallback in practices and by so performance, helping sustain the achieved improvements. In addition, as the main principle of the 2SL approach and the pinnacle of the TPS system, Lean standardization creates a channel for communal contribution to organizational problem solving, In addition to standardization, and in part to the successful implementation of it as well as its goals, management and leadership support are crucial in facilitating the problem-solving organizational culture necessary to drive continuous improvement through communal contributions to the described practices. This support is achieved through sufficient training of both the workforce and the leadership; latter of whose perspective should be pivoted to be transformational. This resource allocation to people development should come as an emphasis in driving organizational change, not only as a critical CSF but also as modern research put forth by international governing agencies so incentivize in pursuit of maintaining human-centrism in value-creating operative systems.

These factors apply to both Lean and I4.0 and can be considered as answers to RQ1: standardization affects progressing in L4.0 maturity by enabling its development through stabilizing operations in its wake, after which it is utilized in improving them and sustaining asserted changes. In addition, Lean standardization practices create a channel for workforce engagement, contribution, and uphold of a performance-optimizing organizational culture, considered critical for the changes that both Lean and smart manufacturing impose.

Due to the gaps found between I4.0 innovations and SOPs, the literature review did not provide sufficient answers for RQ2. Thus, the analysis of this thesis regarding it relies on the empirical research conducted per the methodology.

3 Methodology

This thesis was performed in the form of a case study. The main structure of the methodology was comprised as per Eisenhardt (1989, p. 533-542); a mixed method was used for information acquirement, combined both quantitative and qualitative data through within-case analysis, used deliberate sampling in the case company, reflected empirical findings in comparison to current literature, and generalized findings for academic benefit. The main limitation of this thesis was the use of only one case company, ABB IEC LV Motors Vaasa, which limited said generalization. The following data was analysed with the following methods:

- ABB IEC LV Motors Vaasa: internal documents, on-site observations, and free-form interviews examined in reflexive thematical analysis.
- GembaDocs tool software: on-site observations and free-form interviews examined in reflexive thematical analysis.
- GembaDocs Lean score: survey data from approximately 700 participants examined in descriptive and correlational statistical analysis.
- Eight-hour long GembaDocs pilot test at ABB IEC LV Motors Vaasa: on-site observations examined in reflexive thematical analysis, and survey data from eight participants examined in descriptive and correlational statistical analysis.

The main analysis method of qualitative data was reflexive thematic analysis, which differs from normal thematic analysis in allowing interpretive and flexible analysis of the empirical findings through personal reflection of the researcher in comparing cases to subject field norms (Byrne, 2022, p. 1392–1393). The personal knowledge base used for this reflection was in the context of this thesis its literature review.

In addition, the reliability of research results is to be assessed on behalf of the statistical methods in the results section of this thesis, and of all methods in the conclusion and discussion portion of this thesis.

3.1 Assessing Lean SOP impact in the case company's Lean maturity

The main case company, ABB IEC LV Motors Vaasa, was examined qualitatively through their Lean development strategies and benchmarking of internal SOP practices to set a point of comparison for L4.0 SOP impact assessment. This examination assessed the used forms of SOPs, their creation, editorial, approval and publication practices at ABB IEC Motors Vaasa, as well as their planned phases of development in their Lean transformation. This was performed through internal documents and on-site observations of the internal ABB intranet environment, as well as free-form expert interviews. These findings were then assessed in the comparative context of the literature review through reflexive thematic analysis.

To gain a quantitative perspective of the L4.0 SOP implementation's impact, a pilot group test was conducted at the case company per an A/B test basis. Like described by Quin et al. (2024, p. 1–3), the test sought to test to variants of the same function, i.e. the current SOP techniques, formats, and processes, and that of GembaDocs, the chosen L4.0 tool, and was performed in three phases:

1. The design phase, planning the test: hypotheses were placed on L4.0 SOPs being the preferrable, faster and easier way-of-working solution. Duration of the test was set to one workday (i.e. 8 hours), and sample population to eight workers from diverse fields. The test duration and sample size were determined by acquiring as much time and many participants as possible without hindering ABB IEC LV Motors Vaasa's daily operations. Metrics used were durations of chosen tasks and user feedback through user experience and comparison of the two test variants.
2. The execution phase, performing the test: with both test variants, participants created SOPs chosen beforehand and tested utilizing them at the intended point of use. To contrast Quin et al. (2024, p. 2) who describe to split the sample population to the test variants was left undone due to the diversity of the chosen SOPs and the relatively small sample size. The metrics were recorded by each

participant timing their performance of the tasks and answering a survey comparing their performance and preferences between the test variants.

3. The evaluation phase, comparison to the hypotheses: after performing the test, the gathered data was compared to the hypotheses. In addition, lessons learned were collected through the survey and discussion with the population to aid in the L4.0 SOP tool implementation and the ongoing Lean transformation. Comparison of the test variants was displayed through descriptive analysis of the recorded metrics.

3.2 Assessing modern SOP potential in L4.0 transformations

To gain insight to L4.0 SOPs and their potential, the related tool GembaDocs was assessed. The functions and capabilities of the GembaDocs L4.0 SOP tool was analysed in the context of the literature review through reflexive thematical analysis.

In addition, GembaDocs Ltd provided this thesis with two survey datasets, each comprising of around 700 answers to a variety of Lean maturity metrics. The data of this dataset was analysed to find both descriptive statistics and correlations between factors connecting success in Lean implementations with that of L4.0 SOP implementation. Since the data is structured in ordinal or rank-based variables, the Spearman correlation coefficients were calculated as the most suitable equation between all variables, with the following formula (Wiśniewski, 2022, p. 152–155):

$$r_{ij} = \frac{\sum_{t=1}^{n}(x_{it}-\overline{x_i})(x_{jt}-\overline{x_j})}{\sqrt{\sum_{t=1}^{n}(x_{it}-\overline{x_i})^2 \sum_{i=1}^{n}(x_{jt}-\overline{x_j})^2}},$$

where

x_{it} = variable *i*'s observation t

x_j = variable *j*'s observation t

$\overline{x_i}$ = the mean of variable *i*

$\overline{x_j}$ = the mean of variable *j*

t = the observations index from 1 to n

n = the number of observations.

3.3 Literature review: reflexive comparison

As per Eisenhardt (1989, p. 533), a broad literature review was conducted to compare the described empirical results to build validity of findings per reflexive thematic analysis. Literature gathering was performed from the following sources:

- Multiple research databases, like Elsevier, ResearchGate, Taylor and Francis, and EBSCOhost.
- Professional Lean literature and independent subject publishers, for example essential works like Liker's The Toyota Way (2004), and 2 Second Lean sources like Hughes' G.R.E.A.T. Processes (2023) and Akers' 2 Second Lean (2021).
- A research list provided by the thesis supervisor, consisting of some of most recent and most cited research, research concerning impacts, information and communication, and other research regarding L4.0, and Lean and I4.0 combinations.
- The AI-assisted academic search engine Keenious, which was utilized with prompts like the following: "find me research connecting x with y".

All digital sources were utilized with combinations of the abbreviations list items used as keywords. In addition, as per the individual-reflective nature of reflexive thematic analysis, personal Lean experience was considered where suitable and backed with the above-described sources.

4 Results

The research outlined in the methodology was pursued to find the significance of Lean SOPs and standardized work in developing Lean maturity in modern and digitally integrated organizations. To assess this significance, the main perspective focused on possible I4.0 SOP impacts on the case company, ABB IEC LV Motors Vaasa. Analysis starts at of the case company, progressing onto the capabilities of the chosen L4.0 SOP tool, and concluding with the outcomes of its implementation test.

4.1 ABB IEC LV Motors Vaasa

ABB IEC LV Motors Vaasa, the case company of this thesis, is a branch of the global technology group ABB located in Vaasa, Finland, and it produces electric motors for industrial applications in variable sizes. The company is currently undergoing a Lean transformation initiative, the objective of which is to optimize the organization's operative performance from the perspective of manufacturing and its supporting functions. The current initiative began in early 2025 and can be perceived to be in its early stages. In addition, strategic objectives of the organization include introducing smart manufacturing to their systems by 2030, effectively resulting in a L4.0 organization.

4.1.1 Current standardization system: SOP practices & visual management

ABB IEC LV Motors Vaasa utilizes various forms of SOP documentation and instructions in its operations, dependent on their external and internal requirements, as well as their intended use and point of. Although not officially distinguished, the levels of documentation in the current standardization system can be roughly divided into three categories: management system documentation, dynamic documentation, and loosely controlled instructions. Figure 9 portrays the ordinal relationship between the categories, where control of the documentation increases when ascending in the categories.

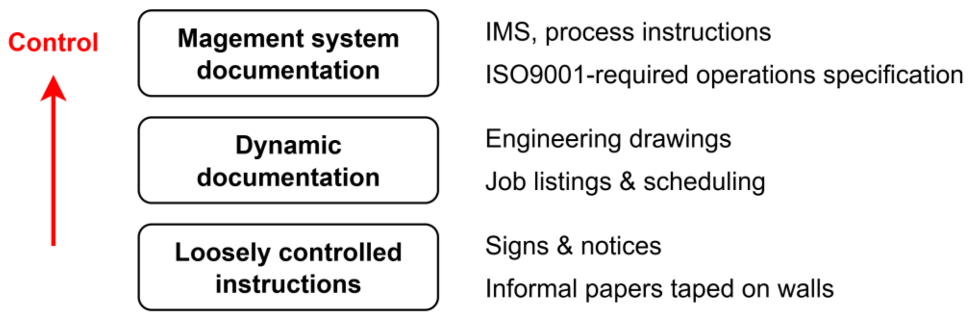


Figure 8. Current standardization practices & visual management at ABB IEC LV Motors Vaasa (made by author).

4.1.1.1 Management system documentation

The management system at ABB IEC LV Motors Vaasa is designed per the ISO9001 framework, and its management system documentation is on most part aligned with its specifications: controlled documentation requires responsible ownership, checking and approval processes, and information regarding revision history. Management system documentation and its virtual upkeep applications are centralized in a Microsoft SharePoint -hosted integrated management system (IMS) intranet platform. As per ISO9001 expectations, content described in the management system documentation resembles closely what Liker & Meier (2006, p. 118–122) describe as forms of standardization differing from Lean standardized work: work standards, process methods, standard procedures.

Whereas the contents of the IMS documentation fulfil the ISO9001 criteria, the level of detail documented vary; some documents of the same operational significance list the work sequence step-by-step, whereas others describe only the general process. Another associated problem within the IMS documentation is occasional vagueness and lack of visual content: for specific examples, a long work sequence description in a controlled document lacked any form of imagery or visual aid, and another instructing to heat components failed to provide any sort of specification like suitable temperature, duration, and equipment (ABB IEC LV Motors Vaasa, 2026b, 2026a). These issues resulted in low utilization by the workforce, and less empowerment of contributing to continuous improvement due to the lack of connection with the instructions, as well as the rigid nature of management system documentation. By extension, the limited utility of these instructions at the intended point of use had led to a dependency of knowledge by experience, which caused system unreliability, different customed ways-of-working, and variation in the performance and quality of operations.

4.1.1.2 Dynamic documentation

Dynamic documentation can in the context of ABB IEC LV Motors Vaasa be narrated as instructions and information in a standardized format, with lower yet moderate control when compared to the management system documentation and characterisation of time-subjectivity. For example, project- or order-specific engineering drawings and assembly instructions require adherence to a standardized format as well as their own checking and approval processes, yet are not housed within the centralized IMS but rather an engineering-designated platform specialized for the intended purpose. The purpose of this separation is in the clarity and fluency of the process: the separate platform also receives and delivers work orders, and standardized drawing items located in the same environment enhance workflow.

The dynamic documentation had issues of its own. To elaborate on the example above, the nature and format of engineering drawings caused similar gaps in information to that which was described for the management system documentation. This contributed negatively to the dependency of information by experience, resulting in the engineering function receiving reoccurring queries over the same assembly steps, causing unnecessary and time-consuming back-and-forth exchanges, which in turn induce variation and strain in the inflicted operations.

4.1.1.3 Loosely controlled instructions; main shortfall of the documentation system

The category with the lowest control was the loosely controlled instructions. These included for example safety signs and notices, as well as informal papers taped to walls of workspaces. Whereas the signs and notices were instated by the management system and their content nature of basic safety practices required little control, the informal papers were not enforced instructions: for example, the brief contents on such papers were simple reminders, how to perform specific activities, what not to do etc. These instructions were posted by the workforce, and their timeliness, correctness nor effectiveness were in no form upkept nor checked.

The signs and notices upholding the health and safety system bore no issues to the informal system. The main shortfall of the loosely controlled instructions was in that they were the only effective outlet for workforce contribution to instructions practical at the intended point of use. In addition, since these instructions were scarce, the information system resembled figure 3 closely: the main instructive input to the workforce came from the management system documentation, to which they had little to no contribution.

The issues of the current information system are illustrated in figure 10. In conclusion, information gaps both in detail and in visuality caused most of the tangible repercussions, like variation, strain, repeated work, and overall operational waste. The main intangible effect of the system was the little inclusion of the workforce in standardization practices, which resulted in SOPs providing little utility in continuous improvement, as well as no engagement, empowerment, nor motivation to contribute to it by the workforce. Thus, it became apparent that improving the standardization system was not only crucial for Lean development in performance stabilization, but also in culture and people building to facilitate their contribution to continuous improvement.

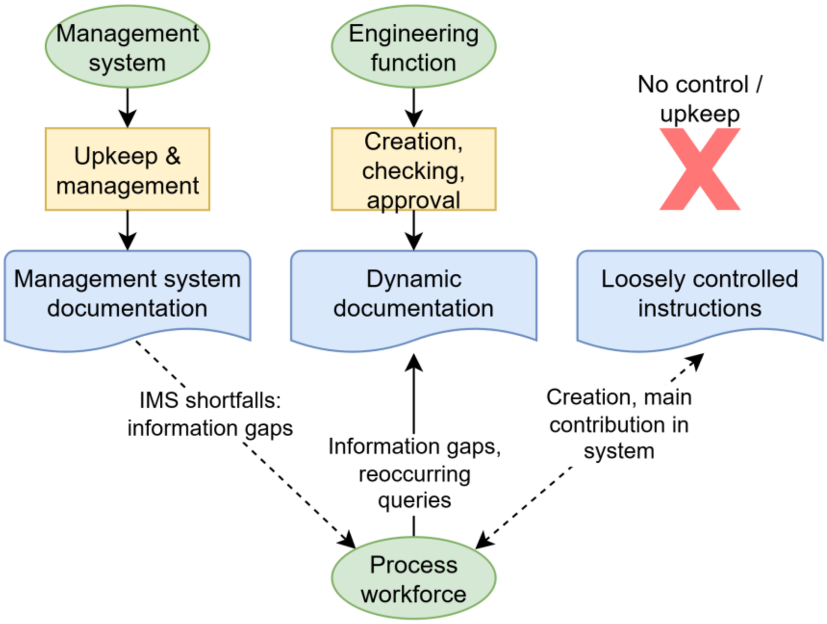


Figure 9. Main issues of the current ABB IEC LV Motors Vaasa standardization system (made by author).

4.1.2 Planned changes: Lean transformation, standardization system overhaul

Like mentioned above, the transformation initiative started in early 2025 and is at the time of this thesis in its early stages. The main operational issues of ABB IEC LV Motors Vaasa have been the unpredictability and disruptions of performance, which the transformation seeks to mitigate.

Figure 11 is an excerpt from their internally used training materials, depicting the different stages of their planned performance development (ABB IEC LV Motors Vaasa, 2026g). The black curve indicates the operative performance level, and its systematic development consists of four main stages:

1. The initial setting, the starting point. Operations are not standardized, which causes variation in quality and fluency of work, and the level of outcome is dependent on the person delivering it. Performance level fluctuates unpredictably. This stage is proceeded from through operations standardization, which commonizes operating procedures and reduces variation.

2. The commonized stage. Standardization has commonized operating procedures, yet problems momentarily drop the performance level. Sustaining improvement through corrective actions and developing standardization to prevent similar problems in the future further stabilizes performance.
3. The stabilized stage. The elimination of variation and problems have resulted in stabilized and predictable performance.
4. The continuously improving stage. After stabilizing performance closer to its stable level, the level itself is raised through improving and altering operations. These changes are updated to the standardization in help to sustaining newfound results.

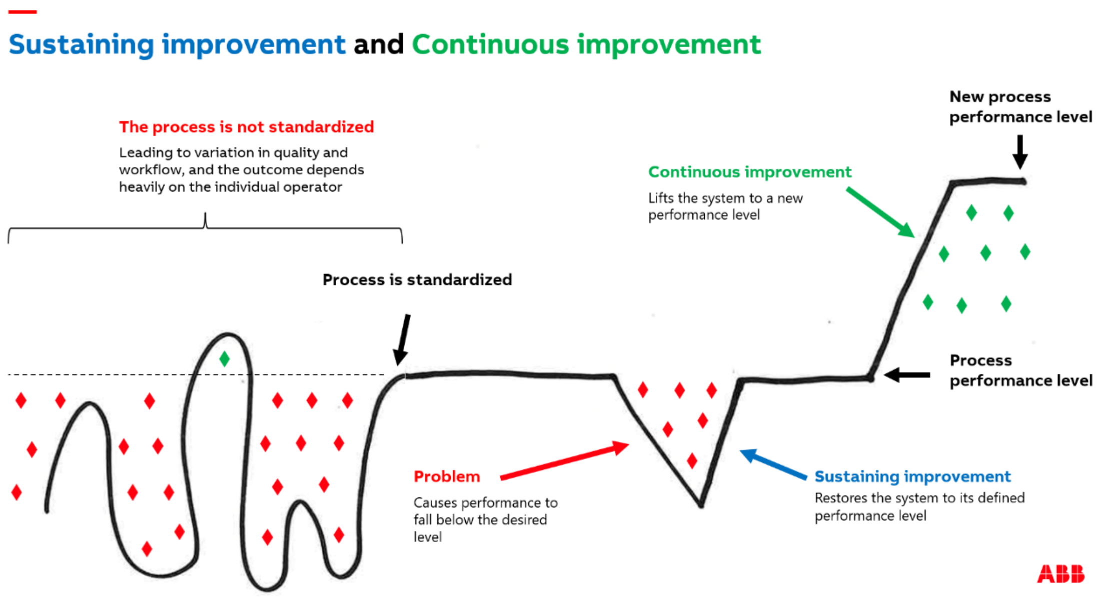


Figure 10. Lean transformation plan regarding performance improvement **(ABB IEC LV Motors Vaasa, 2026g)**.

In assistance to the development of the performance level, other CSFs are assessed through implementations of different Lean principles and methods: for examples, leadership and the workforce are trained in Lean thinking and methods like waste identification and Kaizen improvements, stability is further enhanced with methods like workload-levelling Heijunka, and WIP levels are decreased through kitting and Kanban practices. The role of standardization is emphasized in relation to these methods: before major changes to the operative system, performance stability is crucial and achieved through process standardization.

As their approach for improving their standardization system, ABB IEC LV Motors Vaasa have decided to utilize the Lean standardization software GembaDocs, whose capabilities are examined separately in subchapter 4.2. This tool adoption is aimed to address the issues regarding the weak standardization engagement with the workforce and lack of control of the loosely controlled instructions as illustrated in figure 10 while replacing the prior category's informal paper format. In addition to GembaDocs, ABB IEC LV Motors Vaasa is seeking to implement a new digital manufacturing execution system (MES) to digitally integrate and bridge the enterprise resource planning (ERP) system with the manufacturing environment through monitoring and documenting its processes for example through checklist-formatted process control. Inside the MES checklists, documents produced with GembaDocs can then be integrated to depict the correct progression of specific work sequences. These applications address the issues presented in figure 10 as depicted in figure 12.

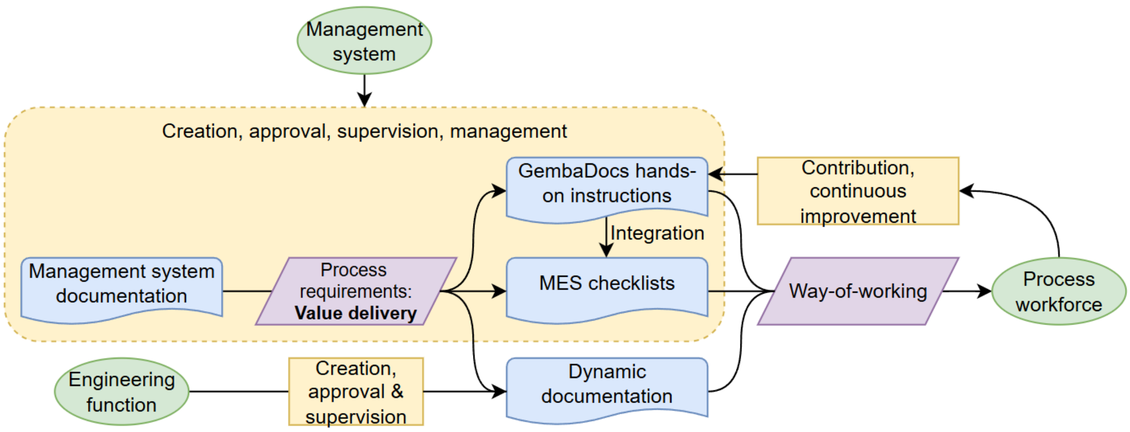


Figure 11. The new standardization system at ABB IEC LV Motors Vaasa (made by author).

4.1.3 ABB IEC LV Motors Vaasa parallels to the literature review

Both the issues and the transformation approach resonate with the findings of the literature review. To start with the planned development of the Lean transformation (ABB

IEC LV Motors Vaasa, 2026g), the performance level development plan illustrated in figure 11 and its different stages bear significant similarities to the examined Lean development models, namely the Torkkola (2018, p. 72–78) steps for improvement. Figure 13 compares the illustrations of both the Torkkola model and the ABB IEC LV Motors Vaasa plan, in which an additional segmentation of the latter is supplemented as per the Torkkola model's stages. As can be observed, the stages of the models share the same characteristics as well as necessary actions for progression. In addition, L4.0 CSFs named by Bueno et al. (2023, p. 8), like continuous improvement programs, learning management, and system connectiveness are in active efforts to be achieved through the mentioned training programs and standardization system upgrades.

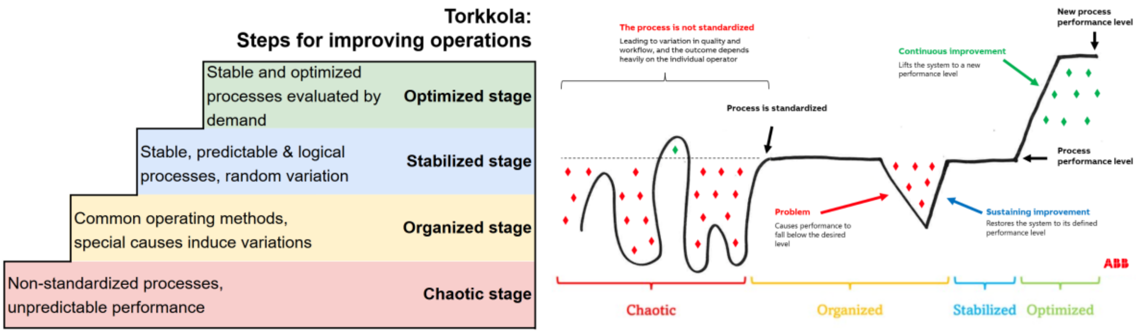


Figure 12. The ABB IEC LV Motors Vaasa improvement model with the Torkkola steps for improving operations (ABB IEC LV Motors Vaasa, 2026g; Torkkola, 2018, p. 72–78).

Smart manufacturing implementations are considered as a future initiative at ABB IEC LV Motors Vaasa. The scheduled start of this initiative is set to approximately five years after the start of the Lean transformation, which is often quoted as an approximate duration of impactfully implementing Lean (Chiarini & Brunetti, 2019, p. 1094; Komkowski et al., 2025, p. 611; ORCA LEAN, 2025). With this consideration, this transformation to an eventually L4.0 system can be perceived as Lean emphatic, where critical operational waste has been eliminated and continuous improvement and learning programs implemented before smart machinery acquisitions, demonstrating the criteria fulfilment of peak Lean maturity. However, the implementation of I4.0-integrated Q4.0 tools like GembaDocs demonstrate a gradual system integration of modern digital capabilities. Such gradual implementations of embracing modern capabilities can also be viewed as overcoming L4.0 barriers and CSFs per Bueno et al. (2023, p. 8) like implementing Lean first and improving system understanding, as well as developing L4.0 maturity factors per Treviño-Elizondo et al. (2023, p. 13–18) like spreading I4.0 awareness and developing necessary I4.0 competencies. With these considerations, the Lean-based L4.0 approach can be illustrated via Figure 14, where peak Lean maturity is achieved before major I4.0 integrations, yet is partly facilitated by Q4.0 implementations.

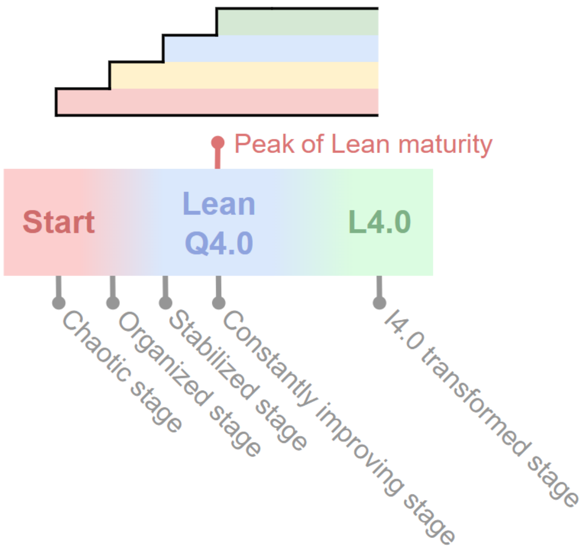


Figure 13. Lean emphatic gradual L4.0 development (made by author).

4.1.3.1 The standardization system: issues and solutions

The issues within the prior system resemble typical examples in traditional Lean literature. For example, the reliance on long worker experience that ABB IEC LV Motors Vaasa experiences resembles what Hughes (2023, p. 21–32) describes as tribal knowledge, a phenomenon in which specific people can form to resemble operational bottlenecks, which the implementation of G.R.E.A.T. process aspects seeks to mitigate or eliminate. In addition, the waiting that the gaps in knowledge induced by the current standardization system causes and the unnecessary repetition of instruction queries can be perceived as Lean waste (Liker & Meier, 2006, p. 35–36), and the variation in un-standardized work caused by individual work preferences is stereotypical for the early stages of the examined Lean development models.

The new standardization system and its features as the solution for these issues resembles in ensemble the description of Lean standardized work by Liker & Meier (2006, p. 113–135), yet differs in some exact qualities. Although the combination of the dynamic documentation, the hands-on instructions and the MES checklists create cohesive and visually supplemented way-of-working instructions, the standardized work sheet as implemented at Toyota features recordings of work step durations, walking time durations between steps, and either a diagram of the work movement or a chronological display of their time usage (Liker & Meier, 2006, pp. 126–130). However, this difference can be due to the different utilization contexts: the MES checklists and GembaDocs instructions are to be easily and frequently utilized by the workforce, whereas Toyota locates their standardized work sheets facing outward of the workstation for public visual management and efficient auditing. By extension, the lower level of detail, for example the exclusion of work step walking durations in GembaDocs, reflects the 2SL approach by which the SOP tool is designed: the use of GembaDocs is made to be easy and available at the point of use for the workforce to enable their engagement with it (Hughes, 2023, p. 27–28).

In addition, it is important to note that whereas Liker & Meier (2006, p. 118–122) describe standardized work as the main form of Lean standardization, they do not denounce the other forms, for example work standards and process standards, but rather acknowledge their different roles in a standardization system. These forms of standardization are to remain housed in the IMS while GembaDocs is purposed as the utility for standardized work practice and workforce engagement. The role of the MES checklists is to operate as a medium in ensuring sustaining standardized practices further stabilizing performance, to be controlled by the management system and actively utilized by the workforce. Figure 15 illustrates the relationship between the different standardization forms and their associated tools, and how the roles of the workforce and the management system differ between them.

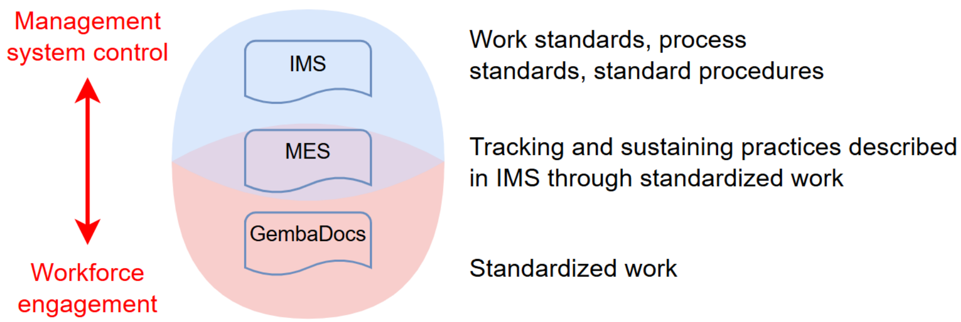


Figure 14. Standardization system tool roles (made by author).

4.2 GembaDocs: L4.0 SOPs

GembaDocs is a digital Lean standardization tool by Tom Hughes, a central author in the 2SL field of literature. By result, the main design principles of the tool reflect typical 2SL approaches, like people-centrism and continuous improvement through communal engagement and contribution. The tool has integrated different I4.0 qualities, and by thus contributes to the I4.0-digital integration of organizations implementing it. To provide context for the pilot test conducted at ABB IEC LV Motors Vaasa in relation to their ongoing Lean transformation, the technical capabilities of GembaDocs are assessed. In addition, the Lean score datasets GembaDocs Ltd. surveyed from their stakeholders and client prospects is analysed for Lean factor descriptive and correlational statistics to find aspects to prioritize in Lean implementations to modern business environments.

4.2.1 The GembaDocs operating system: I4.0 integrations

The operating system of GembaDocs is centered on the factors of G.R.E.A.T. processes and standardization acronym, which it achieves mainly through easy SOP creation, updating, displaying, and management. The tool software operates as a standalone application, as well as a web-hosted platform, alternatives through which the tool can be accessed through both computers and personal devices like smartphones and tablets. Three main utilization methods are purposed for the SOPs created in GembaDocs: as publicly posted hands-on instructions, Kanban cards, and Kamishibai cards, all of which operate in a similar method.

From the user perspective, GembaDocs SOPs are utilized through documents posted to workstations, which either include a QR-code to access the digital SOP or the whole standard document. The QR-codes are to be read through a personal or the work-station's smart device or barcode reader, which directs the associated device to the digital SOP housed in a cloud storage system. In this digital view, the user can either comment on the document or with sufficient profile permissions edit it, thus applying SOP improvements at the intended point of use. The SOPs can also be accessed and applied administrative control to directly in the GembaDocs application in a smart device or through their website. Regarding the I4.0 aspects of this system, it can be perceived as a CPS, where the publicly posted QR-codes, SOPs, and the devices they are accessed with form the physical part of the system, and the cloud storage system forms the cyber part. Figure 16 illustrates this division of the parts in the system. In addition, the digital format of the SOPs enables video inlay into the same documents, a quality with effective resemblance to little SOP tools prior.

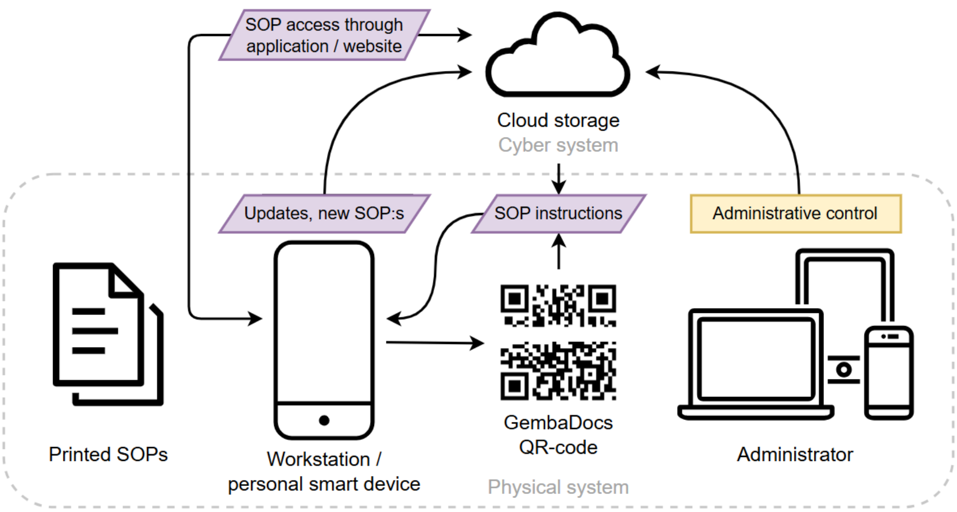
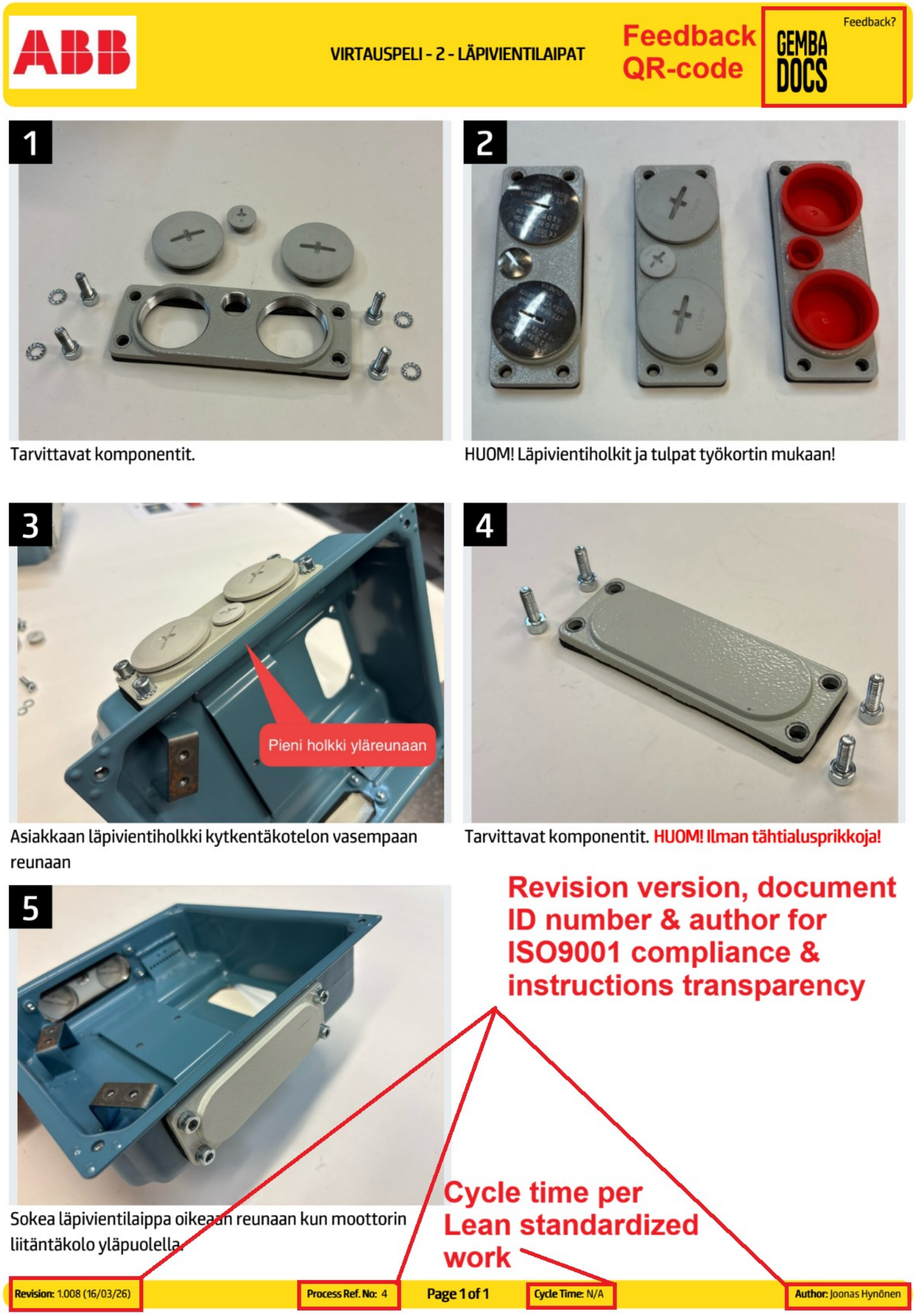


Figure 15. The GembaDocs SOP CPS (made by author).

From the perspective of the management system or the entity creating the SOP instructions, the I4.0 integrations of the tool come apparent in streamlining the ease of use: the tool has AI integrations applied to many editing capabilities, like automatic video editing, content reshaping, text-to-speech conversion and more. The cloud storage system operates as a central file location, which enables the organization of SOP filing where the same documents can appear in multiple subject area folders without storing multiple duplicates of it. This prevents the display of dated instructions while ensuring sufficient ensembles of necessary instructions for specific task clusters and teams. In addition, ISO-accordant checking and approval functions are built into the tool to ensure ISO9001 compliancy.

Picture 1 displays a process SOP produced with GembaDocs as a test at ABB IEC LV Motors Vaasa, in its printed or computer-display format (ABB IEC LV Motors Vaasa, 2026f). As can be seen from the document, all key steps of the process are pictured and briefly described. For compliance to ISO9001 documentation requirements, metadata like document revision version, reference or identification number, and author are displayed in the document. For the Lean and 2SL connections of the SOP, a feedback QR-code is displayed for suggesting instruction corrections and updates, as well as the intended cycle time for the pictured process. This printed or computer-displayed format displays all the process steps fitting to a single page in one view, whereas picture 2 demonstrates the view in a personal smart device: for sufficient formatting, the smart device view displays one process step at a time (ABB IEC LV Motors Vaasa, 2026e). Lastly, picture 3 displays the QR-code-only format of posting the SOP at the intended point of use as shown in picture 4, purposed for purely digital access to the instructions (ABB IEC LV Motors Vaasa, 2026c, 2026d).



Picture 1. A GembaDocs test SOP, whole format (ABB IEC LV Motors Vaasa, 2026f).

Picture 2. A GembaDocs test SOP, mobile format (ABB IEC LV Motors Vaasa, 2026e).

Picture 3. A GembaDocs SOP, QR-code-only format (ABB IEC LV Motors Vaasa, 2026c).

Picture 4. GembaDocs QR-code-only SOPs posted at the point of use (ABB IEC LV Motors Vaasa, 2026d).

4.2.2 GembaDocs Lean score data analysis

GembaDocs ltd. supplied this thesis with two datasets of the same survey: one conducted in the GembaDocs application software, and another in their public websites through a service called HubSpot. The survey calculated an approximate Lean maturity score on a scale of 0-100 from the respondents' evaluations of 10 Lean characteristics evaluated between 6 ordinal values. The characteristics were as follows:

1. Candour. Issues in the organization are spoken up of, and the workforce are encouraged to do so.
2. Top leadership commitment. Management support for Lean and implementation in leadership practices.
3. Change the people or change the people. An organizational culture-building principle by Hughes (2022, p. 55–67), signifying either cultivating Lean acceptance within the existing workforce or recruiting acceptive people while removing ones resisting.
4. Employee engagement. Communal contribution to daily Lean practices.
5. Education. Regular education initiatives for the workforce both in general and in Lean thinking.
6. Kanban for inventory management. Kanban operating system implementation.

7. Continuous skill development. Training, tracking and competency mapping of such.
8. Recognition. Acknowledging of personal and communal Lean achievements, successes, failures and development opportunities.
9. Standard work. Implementing effective and cohesive standardization accordant to the 2SL G.R.E.A.T. acronym qualities.
10. Visual management. The use of visual systems in guiding operations.

In addition, dataset 2 from HubSpot included the respondents' relationship with GembaDocs: in the following tables, value 1 in the "status" variable signifies respondents as potential leads for GembaDocs subscription, whereas value 2 signifies ready tool customers and subscribers. Some limitations to the analysis were also realized: respondents' overlap to both datasets was technically possible, as was the change of potential GembaDocs leads changing to full customers.

4.2.2.1 Descriptive analysis

The two datasets behaved very similarly in their descriptive qualities, as presented in table 1 with connected heatmapping to display total relationships. Average Lean score of all respondents is approximately 51 out of 100, signifying established foundation of operational maturity yet room for development. In both datasets, respondents evaluated themselves the highest in top leadership commitment, and the lowest in utilizing Kanban inventory management practices. The respondents evaluated themselves lowly on average in standardization practices, scoring the second lowest values in both datasets. The most notable difference between the datasets would appear to be the mode distribution in the Kanban practices, a change however only minimal in perspective: the evaluation distributions of the variable in both datasets are very similar, displaying only a discrete increase in value 1 evaluations in dataset 2 as displayed in figure 17.

Both datasets, all respondents' descriptive statistics: connected heatmaps

Dataset 1 - all	N	Mean	Median	Mode	Sum
Overall Score	288	51,53	52	46	14842
Candour	288	3,82	4	3	1101
Top Leadership Commitment	288	4,02	4	6	1159
Change the People or Change the People	288	3,9	4	4	1122
Engagement	288	3,42	3	3	986
Education	288	3,5	3	3	1008
Kanban for Inventory Management	288	3,19	3	4	919
Continuous Skill Development Score	288	3,35	3	3	966
Recognition Score	288	3,77	4	4	1085
Standard Work	288	3,32	3	3	956
Visual Management	288	3,47	4	4	999

* 1 = lead, 2 = customer

Dataset 2 - all	N	Mean	Median	Mode	Sum
Overall Score	270	51,28	51	46	13846
Candour	270	3,8	4	3	1026
Top Leadership Commitment	270	4,01	4	6	1082
Change the People or Change the People	270	3,87	4	4	1044
Engagement	270	3,44	3	3	928
Education	270	3,5	3	3	945
Kanban for Inventory Management	270	3,2	3	1	863
Continuous Skill Development	270	3,36	3	3	906
Recognition	270	3,74	4	4	1010
Standard Work	270	3,29	3	3	889
Visual Management	270	3,44	4	4	930
Status*	270	1,3	1	1	352

Table 1. Both datasets' all respondents' descriptive statistics, connected heatmapping (made by author).

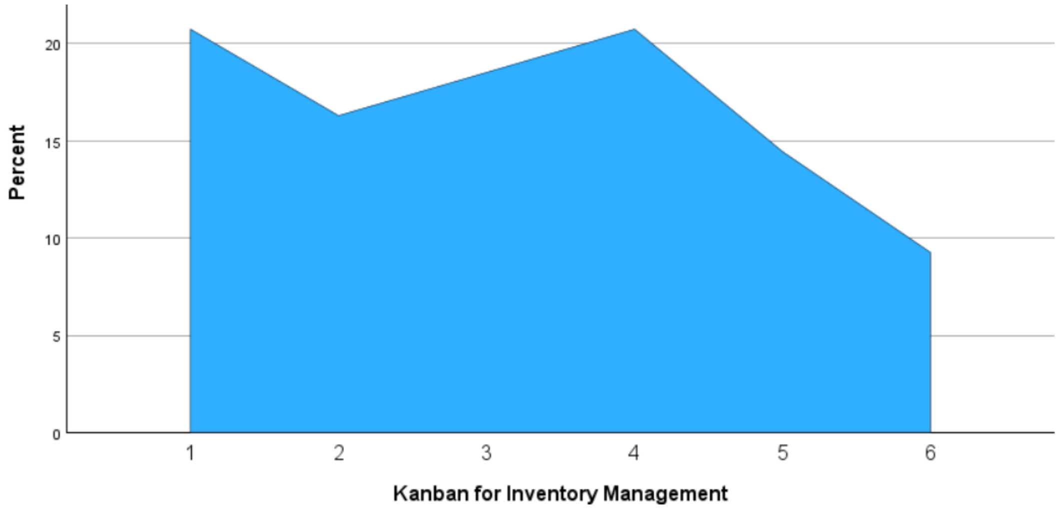


Figure 16. Kanban variable evaluation distribution in dataset 2 (made by author).

To further assess the different impacts of the characteristics in successful Lean maturity initiatives, dataset 2 was examined with comparison to its highest 25 % and its lowest 25 % overall score respondents. This comparison is presented in table 2, where heatmapping is individual to the tables to display the strengths and weaknesses of both groups.

The average overall score of the top 25 % was 79,5 out of 100, and 24,06 for the bottom 25 %. The two groups presented different strengths and weaknesses: the main strength of the top 25 % was top leadership commitment, whereas candour for the bottom 25 %, and the lowest evaluated factor was continuous skill development for the top 25 %, Kanban practices for the bottom 25 %. Standard work is not among the strongest strengths or weaknesses in either group, yet of a clear development when examining higher overall scorers: figure 18 displays the distribution of standard work values over the overall score in dataset 2, displaying a growing trend of SOP practice maturity in higher overall scorers.

Dataset 2, top & bottom 25 % Lean score respondents' descriptive statistics: separate heatmaps

Top 25 % Lean score	N	Mean	Median	Mode	Sum
Overall Score	68	79,5	78	76	5406
Candour	68	5,24	6	6	356
Top Leadership Commitment	68	5,47	6	6	372
Change the People or Change the People	68	5,1	5	5	347
Engagement	68	4,87	5	5	331
Education	68	5,35	6	6	364
Kanban for Inventory Management	68	4,88	5	6	332
Continuous Skill Development	68	4,34	4	4	295
Recognition	68	5,24	5	6	356
Standard Work	68	4,66	5	4	317
Visual Management	68	4,6	5	4	313
Status*	68	1,35	1	1	92

Bottom 25 % Lean score	N	Mean	Median	Mode	Sum
Overall Score	69	24,06	26	34	1660
Candour	69	2,62	3	3	181
Top Leadership Commitment	69	2,28	2	3	157
Change the People or Change the People	69	2,49	3	3	172
Engagement	69	1,91	2	1	132
Education	69	1,93	2	1	133
Kanban for Inventory Management	69	1,72	1	1	119
Continuous Skill Development	69	2,22	2	2	153
Recognition	69	2,43	3	3	168
Standard Work	69	2,16	2	2	149
Visual Management	69	2,26	2	2	156
Status*	69	1,2	1	1	83

* 1 = lead, 2 = customer

Table 2. Dataset 2, top & bottom 25 % Lean score respondents' descriptive statistics: separate heatmapping (made by author).

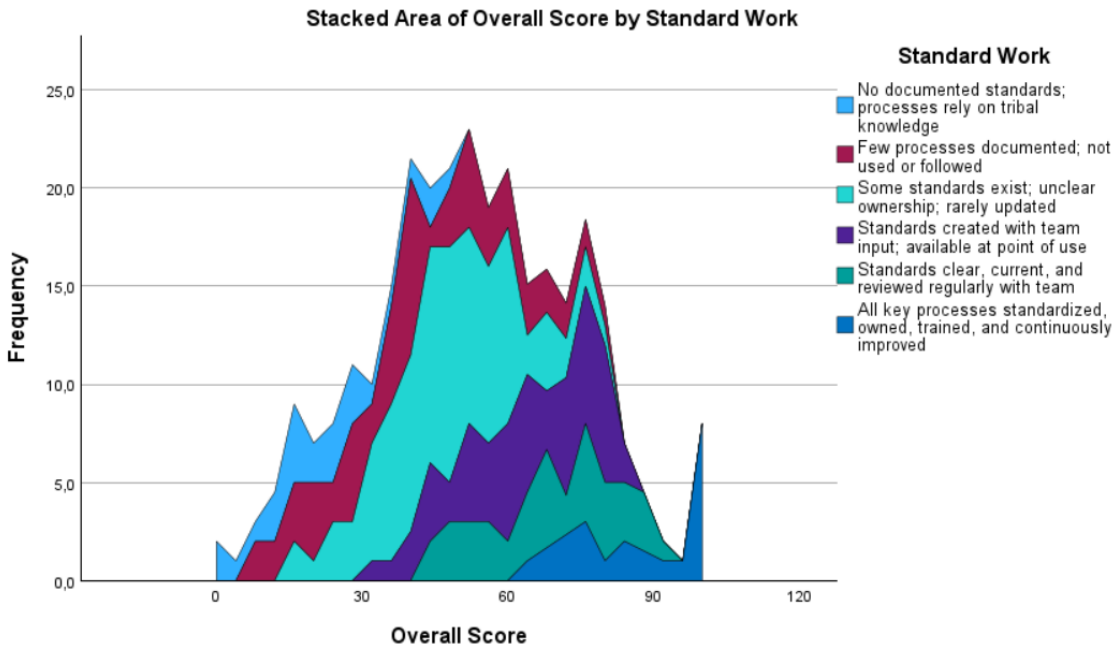


Figure 17. Standard work development over overall score in dataset 2 (made by author).

4.2.2.2 Correlational analysis

Whereas correlation and causation should be assessed as separate phenomena, the correlational relationships between the characteristics can be evaluated as to what factors and their combinations tend to improve upon progressing in Lean maturity. Table 1 displays the Spearman's correlations in dataset 1 collected from the GembaDocs software application, and table 2 displays the correlations in dataset 2 collected from HubSpot. Again, the datasets behaved very similarly, a fact to which the respondent status variable makes little change to; dataset 2 expressed notably non-existent correlations to all other variables with 2-tailed insignificance, demonstrating either a small impact on Lean practices induced by the tool or a saturated sample pool. The possibility of the latter is at a notable level, since access to the survey via HubSpot still happened through the social media channels of GembaDocs, for example their IoT website and LinkedIn profile. Due to this recorded and assessed insignificance, all further analysis of the datasets excludes the lead / customer status from consideration.

GembaDocs application Lean score survey - factorial correlations

Variables	Overall Score	Candour	Top Leadership Commitment	Change the People or Change the People	Employee engagement	Education	Kanban for Inventory Management	Continuous Skill Development	Recognition	Standard Work	Visual Management
Overall Score	1,000	0,739	0,751	0,773	0,783	0,800	0,707	0,676	0,794	0,737	0,695
Candour	0,739	1,000	0,525	0,622	0,485	0,514	0,415	0,443	0,592	0,512	0,477
Top Leadership Commitment	0,751	0,525	1,000	0,572	0,575	0,589	0,447	0,435	0,598	0,403	0,421
Change the People or Change the People	0,773	0,622	0,572	1,000	0,512	0,553	0,449	0,518	0,597	0,520	0,503
Employee engagement	0,783	0,485	0,575	0,512	1,000	0,693	0,554	0,489	0,629	0,508	0,446
Education	0,800	0,514	0,589	0,553	0,693	1,000	0,551	0,475	0,615	0,488	0,501
Kanban for Inventory Management	0,707	0,415	0,447	0,449	0,554	0,551	1,000	0,391	0,475	0,538	0,482
Continuous Skill Development	0,676	0,443	0,435	0,518	0,489	0,475	0,391	1,000	0,504	0,571	0,450
Recognition	0,794	0,592	0,598	0,597	0,629	0,615	0,475	0,504	1,000	0,525	0,489
Standard Work	0,737	0,512	0,403	0,520	0,508	0,488	0,538	0,571	0,525	1,000	0,606
Visual Management	0,695	0,477	0,421	0,503	0,446	0,501	0,482	0,450	0,489	0,606	1,000

Non-significant at the 0,01 level (2-tailed)

Table 3. Dataset 1, GembaDocs application Lean score factorial correlations (made by author).

GembaDocs HubSpot Lean score survey - factorial correlations

Variables	Overall Score	Candour	Top Leadership Commitment	Change the People or Change the People	Engagement	Education	Kanban for Inventory Management	Continuous Skill Development	Recognition	Standard Work	Visual Management	Lead / Customer Status
Overall Score	1,000	0,735	0,765	0,785	0,793	0,814	0,724	0,678	0,804	0,740	0,697	0,071
Candour	0,735	1,000	0,526	0,629	0,491	0,524	0,446	0,441	0,583	0,521	0,471	-0,016
Top Leadership Commitment	0,765	0,526	1,000	0,592	0,582	0,597	0,479	0,446	0,616	0,419	0,458	0,184
Change the People or Change the People	0,785	0,629	0,592	1,000	0,528	0,560	0,457	0,533	0,629	0,548	0,501	0,000
Engagement	0,793	0,491	0,582	0,528	1,000	0,703	0,572	0,491	0,659	0,521	0,470	0,075
Education	0,814	0,524	0,597	0,560	0,703	1,000	0,558	0,501	0,654	0,528	0,524	0,076
Kanban for Inventory Management	0,724	0,446	0,479	0,457	0,572	0,558	1,000	0,411	0,515	0,562	0,481	0,043
Continuous Skill Development	0,678	0,441	0,446	0,533	0,491	0,501	0,411	1,000	0,507	0,559	0,472	0,050
Recognition	0,804	0,583	0,616	0,629	0,659	0,654	0,515	0,507	1,000	0,520	0,479	0,103
Standard Work	0,740	0,521	0,419	0,548	0,521	0,528	0,562	0,559	0,520	1,000	0,606	-0,039
Visual Management	0,697	0,471	0,458	0,501	0,470	0,524	0,481	0,472	0,479	0,606	1,000	0,001
Lead / Customer Status	0,071	-0,016	0,184	0,000	0,075	0,076	0,043	0,050	0,103	-0,039	0,001	1,000

Non-significant at the 0,01 level (2-tailed)

Table 4. Dataset 2, GembaDocs HubSpot Lean score factorial correlations (made by author).

Since the overall score variable is calculated from the 10 characteristics, their correlations with it should be examined with wariness and criticism. However, the order of strength of the characteristics to it can be assessed: Education was found to have the strongest correlation in both datasets to the overall Lean score at 0,800 in dataset 1 and 0,814 in dataset 2. The lowest correlation with the overall Lean score was with continuous skill development at 0, 676 in dataset 1 and 0,678 in dataset 2. The correlation between the overall Lean score and standard work was the seventh strongest in dataset 1 at 0,737, and the sixth strongest in dataset 2 at 0,740. Like mentioned above, whereas these correlations would normally be considered strong to very strong in the Spearman correlation scale, the connection between the overall score calculation method and the characteristics inflates these values and thus disables their evaluation at their nominal values without finding its measurable impact. However, these findings do reflect the descriptive statistics of table 2: education was among the strongest strengths of the top 25 % Lean score respondents and the strongest weaknesses of the bottom 25 %, continuous skill development the weakest strength of the top 25 % yet of a medium significance to the bottom 25 %, and standard work held a similar position of strength in both groups of table 2 and both correlation tables.

For the inter-characteristic correlations excluding the overall score and the status variable, the strongest correlation in both datasets was between education and engagement at 0,693 in dataset 1 and at 0,703 in dataset 2, signifying a strong correlation between the characteristics. The weakest correlation in both tables was between Kanban practices and continuous skill development at 0,391 in dataset 1 and at 0,411 in dataset 2, signifying a weak to moderate correlation. Standard work had strongest correlation with visual management at 0,606 in both datasets signifying a strong correlation, and the weakest with top leadership commitment at 0,403 in dataset 1 and at 0,419 in dataset 2 signifying a moderate correlation. In addition, cumulative sums of inter-characteristic correlations can be assessed: continuous skill development had the lowest cumulative correlation to all others, whereas recognition had the most, excluding the overall score.

4.2.3 GembaDocs parallels to the literature review

Like mentioned in the literature review, the connection between I4.0 and SOP research is non-existent. However, some parallels can be drawn between the GembaDocs assessments and the literature review: the I4.0 integrations of the tool, its operating and visualization system and central design principles, and the results of the Lean score survey.

4.2.3.1 GembaDocs capabilities & the standardized work sheet

As already assessed, GembaDocs and its capabilities are mainly based on the G.R.E.A.T. processes and standardization acronym by Hughes (2023, p. 21–32), and that the acronym's principles themselves are on large part based on the 2SL form of Lean thinking, prioritizing workforce engagement and recognition in building organizational culture (Akers, 2021, p. 38–46). A note can although be done of the importance of the roles of leadership and training in starting efforts to achieve these factors with GembaDocs: since both Lean training and standardization practices are to be initiated at the early stages of Lean implementations, training is to be done to gain method acceptance and mitigate its resistance by the workforce (Torkkola, 2018, p. 73–74).

The two main Lean SOP tools examined in this thesis, GembaDocs and the standardized work sheet from figure 2 by Liker & Meier (2006, p. 127) share many similarities. Firstly, both share common characteristics like sequential process description and intended cycle time, Lean-oriented qualities like process visualization and value mapping, and external requirements enabling qualities like ownership and organizing information. In addition, both tools limit the amount of information that can be input to the SOPs, proving wrong another myth of posted hands-on instructions: the SOPs are to display only the actions producing value, not a comprehensive description of the whole process for its knowledge is expected of the workforce. These similarities highlight the shared general purpose of standardization practices, and furthermore that of Lean standardization:

commonizing operating procedures, stabilizing performance, finding operational waste, and sustaining improvements.

Despite these similarities, more can be assessed from their differences: like mentioned above, no connections between SOP capabilities and possible I4.0 or even digital integrations have popularized in research, thus validating the presumption of solely physical utilization of the Liker & Meier (2006, p. 127) standardized work sheet, or at best a digital filling of the sheet form. In addition, the formatting of the steps and by such the visual capabilities of the tools are different: the standardized work sheet has an easily interpretable overview of the sequence at the workstation yet lacks in detail of the individual steps, a quality which GembaDocs somewhat opposes with greater detail of the steps yet no workstation overview.

The main reason of these differences is the one in their intended purposes as assessed in subchapter 4.1.3.1.: GembaDocs 2SL SOPs are purposed for active utilization by the workforce, and the Toyota standardized work sheets are posted outside the work cells for ease of auditing (Liker & Meier, 2006, p. 122–125). In addition, the technological development of minimum twenty years that has occurred between the conceptions of these tools is to be noted, as much of the technology-scepticism of Lean practices by the likes of Ohno dates even older and is by thus more obsolete. Modern business environments face digitalization in magnitudes unparalleled in the past, and as displayed in figure 15 of the standardization system tool roles at ABB IEC LV Motors Vaasa, digital SOPs can also act as components of larger operations execution systems, in which seamless integration is only possible with digital systems. A note can also be made with the Modig & Åhlström (2013, p. 140–146) means abstraction model: dismissal of technology should not be a goal, but rather the most optimal alternative should be chosen as a mean to advance towards operational excellence, be it digital or physical. With these considerations, as well as that of the also physical capabilities of GembaDocs, the tool can be perceived as both a development partly based on the standardized work sheet, as well as a standardization approach of different priorities.

4.2.3.2 GembaDocs I4.0 features: I5.0 applicability, context to L4.0 development

Many of the central I4.0 technology clusters mentioned by Suleiman et al. (2022, p. 18–21) are implemented in GembaDocs: CPS, AI and cloud technologies. Thus, GembaDocs can be perceived as a Q4.0 tool for its I4.0 integrations, and as per figure 14 of gradual Lean to L4.0 development, a central contributor in a digitalizing Lean transformation. A parallel to this connection can be drawn to the Sjödin et al. (2018, pp. 25–29) digitalization leveraging MM, where the tool fits to the description of most developmental levels: in the starting level 1 by cultivating engaging and change-inclusive organizational culture and connecting new technologies together to improve data flow with the IMS-MES-GembaDocs system, in level 2 with training the workforce in the use of this connected system and helping build knowledge-sharing, in level 3 by supporting the operational knowledge base for the sense-making events, insight analysis and the operations optimization, and in level 4 by operating as a component of the newfound continuous innovation culture and visualization systems.

GembaDocs can also be seen an enabler or early integration component in a human centric I5.0 smart manufacturing system, like that of Peruzzini et al. (2024), since features of the tool extend to many of the domains and layers of this proposed framework: physical copies and QR-codes are accessible in the observable manufacturing domain and its physical layer, workstation or personal devices utilized in accessing or editing the digital copies work as HMI interfaces in connecting trough CPSs to the upper communication domain. With all these considerations, as well as the 2SL organizational culture and people development prioritization forming the basis and the intended use of the tool, GembaDocs can also be seen as a L5.0 driver, promoting modern digital capabilities and accordant environmental system design, Lean practices and communal engagement with them, and by thus the role of people in the core of such systems.

4.2.3.3 Lean score data: reinforcement of the means abstraction model

Whereas possible bias to the 2SL approach to Lean cannot be dismissed, the highlighted factors of the people and culture emphasis further reflect the importance of Lean transformations as that of its people rather than its operations, at least initially. The notably low-scored factor of the only operational Lean method evaluated, Kanban for inventory management, especially in organizations with low overall scores at the beginning of their Lean initiatives and the small correlation to continuous skill development showcase uniformity to the inspected Lean MMs and the development model in place at ABB IEC LV Motors Vaasa, where achieving process stability and culture change come before large operations changes (Torkkola, 2018, p. 72–78). In these people-centric dimensions, the factors seem connected to the assessed Lean CSFs and realized by those further in development, in factors like education, top leadership commitment, engagement, and acceptive staff cultivation. In addition, in pursuit of such culture change the role of transformational leadership and sufficient training as per Kalsum et al. (2024, pp. 57–66) and Veloso-Besio et al. (2019, p. 258–260) seem acknowledged by the majority of Lean implementors.

As noted in the analysis, respondents scored averagely lowly to standardized work in relation to the other factors. This however does not signal a lack of importance for Lean standardization practices, for example since its correlation with the overall score was of a notable strength in relation in tables 3 and 4 as well as of alongside growth as displayed in figure 18. As for the advanced visualization effects of GembaDocs, the data does reflect their importance with the strongest correlation of standard work being with visualization. In addition, and as noted in the previous subchapter 4.2.3.2., Lean standardization does operate also as support to the emphasized people-centred factors as serving as a foundation and platform for communal participation.

4.3 GembaDocs pilot test at ABB IEC LV Motors Vaasa

To examine the efficiency and the potential future impact of implementing Lean workforce-engaging standardized work, a pilot test was conducted in the use of the hands-on instructions tool GembaDocs. The main evaluated aspects of the tool were the creation, editing, and presenting SOPs at the intended point of use, which after performed at the ABB IEC LV Motors Vaasa manufacturing location were evaluated with a survey compiled from the perspective of the G.R.E.A.T. processes and standardization acronym's aspects.

After a brief training to the use of the tool, GembaDocs was found by most participants preferrable to the prior standardization practices in all activities as illustrated in figure 19. The most preference in GembaDocs was found in the G.R.E.A.T. aspect R – Recognized; most participants found GembaDocs to be easier in including the workforce to standardization practices. However, resistance to change and workforce attitudes were speculated as a future challenge, for example as personal threats to the experience-dependency of the prior system and in resistance to utilizing personal devices in accessing the digital SOPs. This speculation resulted in the lowest preferences of GembaDocs utilization, in intended users recognizing the SOPs as their own and useful. This contrast in the recognition aspect is illustrated in figure 20, where most participants found workforce inclusion easier with GembaDocs yet readiness of their collaboration sceptical.

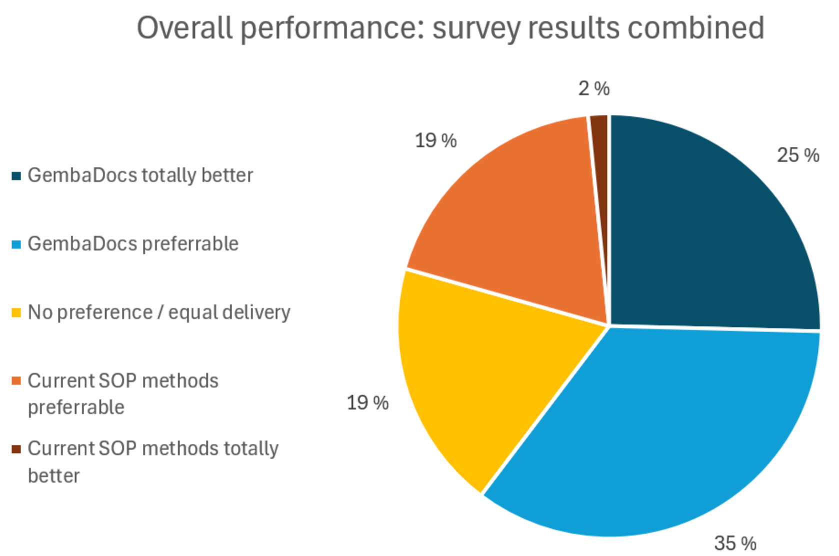


Figure 18. Gembadocs pilot test overall survey results (made by author).

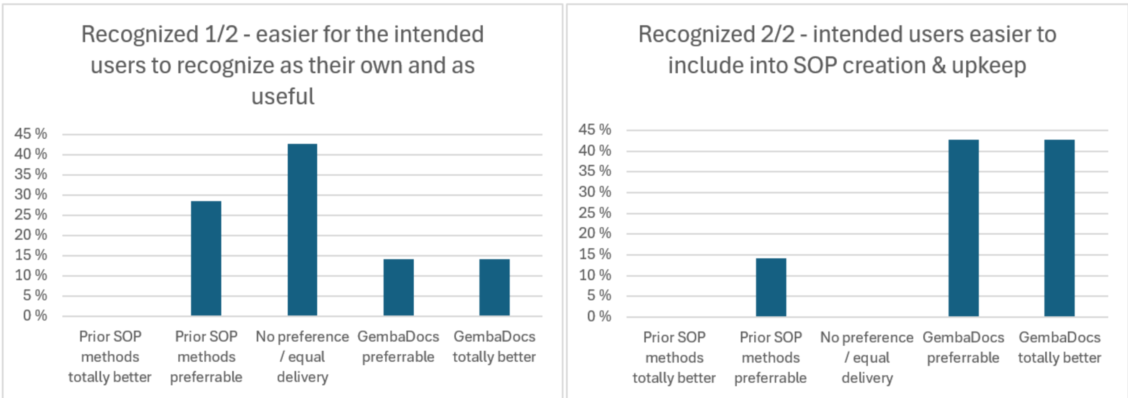


Figure 19. Contrasts in the workforce inclusion (made by author).

4.3.1 Easiness of use as a highlight: impact in overall preference

The difference in ease of use was measured in four aspects: creating, modifying, publishing, and overall utilization of the SOPs. GembaDocs was found preferrable by the majority in all aspects, displaying a right-skewered trend like displayed in figure 21. The most preference was found in the creation of the SOPs, whereas the least in modifying them. Although the SOP creation process has the most advanced utilities in GembaDocs, another reason for these outcomes can be the time management of the test: during the training portion of the test, most attention and time was put to the creation process, whereas editing SOPs was assessed significantly more briefly.

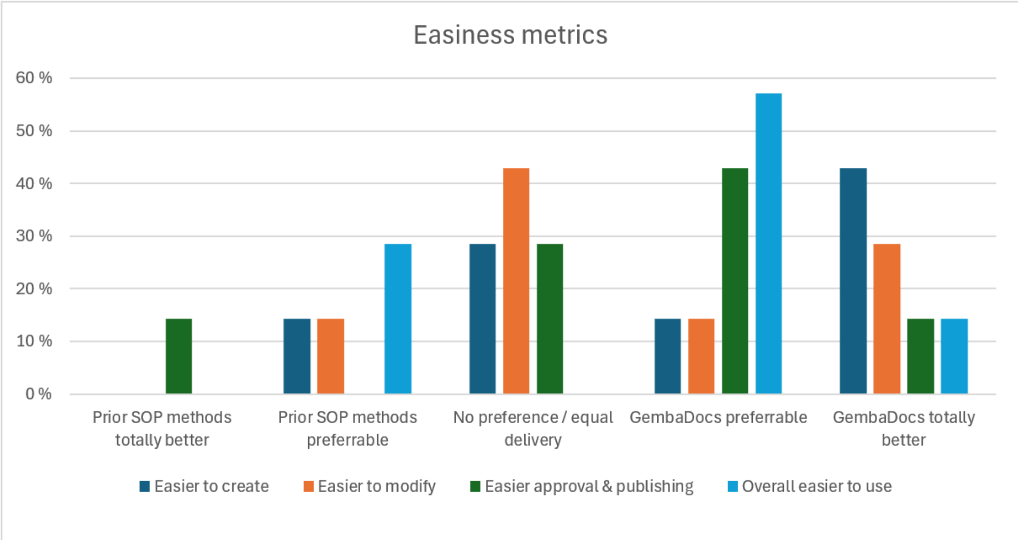


Figure 20. GembaDocs pilot test survey easiness metrics (made by author).

To further display the easiness of use, durations of creating the SOPs with both the new and prior methods were measured by all participants. Utilizing GembaDocs in comparison to the prior SOP methods produced average time savings of 22,52 %, with the highest individual savings at 66,67 % and the lowest at -50 %. In addition, strong correlation, 0,83 on the Pearson scale of 0 to 1, was found between this time benefit and the participants' survey preference averages. For example, the same participant who experienced the lowest durational benefit from GembaDocs also displayed the lowest average preference to it from the test group. This correlation between experience and preference highlights the importance of comprehensive training and process definition to standardization practices: among others, the same participant with the lowest average preference noted clear definition of GembaDocs utilization context as a necessity in the open feedback portion of the survey.

4.3.2 Experienced factors for future development: technical issues in GembaDocs

Although many aspects in the pilot test produced positive findings to the implementation of Lean standardized work through GembaDocs, some issues and factors to develop were also experienced, focusing mainly on technical aspects of GembaDocs: Firstly, the

I4.0 integrations of GembaDocs assessed below produced errors. For example, the AI-driven automatic video editing cut extensive portions deemed necessary to include and lacked the option of processing video material without sound. In addition, automatic text formatting produced problems in the clear alignment and presentation of contents without option to disable the automation.

By extension, the second main factor of future development was the inflexibility of the SOP format. For example, the order of pictures, like that of picture 1, is largely unchangeable in the GembaDocs software. This issue was identified as a crucial factor of future development, since although the G.R.E.A.T. aspect A, available at the point of use, displayed clear GembaDocs preference in the pilot group, when manufacturing shop floor workers were presented with the same instructions in both the prior and the GembaDocs format, most chose the versions produced with the prior practices. The workers credited this preference to the more freely alterable document format of the prior practices, which enabled for example larger text and pictures, as well as more options to their placement and order. For further example, a worker credited their prior SOP practice document preference to a downward continuous progression of process steps enabling larger pictures and a more fluent workflow, whereas the printed format of GembaDocs is limited to two process steps per row thus resulting in smaller display. However, the personal smart device or mobile view of the documents was not compared by the workforce, which has been found preferrable for mobile utilization after the pilot test for similar format priorities.

4.3.3 The GembaDocs pilot test parallels to the literature review

Many of the factors influencing the pilot test from the perspective of the literature review have already been assessed above, although a few notations can be made from the perspectives of Lean SOP tool comparison, resistance to change and developing L4.0.

4.3.3.1 SOP method differences in context of the pilot test

Since the Lean SOP methods of GembaDocs and the Liker & Meier (2006, p. 126) standardized work sheet were compared above, a similar assessment in the context to the pilot test is in place. Although again is to be noted the difference of intended way of utilization between the two methods, the survey results of the pilot test support the pursuit of employee engagement in GembaDocs similar to what is intended with the standardized work sheet: the SOPs are to be created with the aid of the workforce including them in the process, thus enhancing engagement, recognition, and insightful way-of-working. To elaborate, as was found that GembaDocs was preferrable to the prior system in all of the factors of the G.R.E.A.T. acronym, the tool can be perceived as filling all of the criteria of 2SL SOPs: a SOP format utilized with system understanding, is validly recognizable, easy to use, available at the point of use, and operating as tested and trained. The best achievements were based on the survey in the easiness of use, which with its inclusion-enabling cultivates communal participation to Lean practices and by thus organizational problem solving, the pinnacle of Lean systems as per Liker (2004, p. 13).

As also noted in both the assessment of the ABB IEC LV Motors Vaasa Lean approach and the pilot test, this inclusion and insight was much more limited within the prior system. This reflects the difference of a typical ISO management system SOP practice as depicted in figure 2 with no feedback loop or inclusion as a starting point, to be developed to one with such as depicted in figure 3. As for the issues found in the pilot test, whereas the I4.0 related technical issues would not presumably be of issue with the standardized work sheet, the workforce’s expressed preferences would have not likely made the tool a better choice than GembaDocs: larger text, pictures, visualization of the steps, and formatted order of steps are more limited within the standardized work sheet than in that of GembaDocs or the capabilities of the prior system. Thus, it can be deducted that GembaDocs is the most preferrable Lean SOP approach at ABB IEC LV Motors Vaasa, over that of Liker’s & Meier’s.

4.3.3.2 Adequate adoption process to support embracement & L4.0 development

The most clearly expressed negative presumption in the Lean SOP adoption at ABB IEC LV Motors Vaasa was that of resistance to change, both to the operating system and to the use of personal smart devices. In this regard, the importance on thorough training as an adoption prerequisite and part-enabler is reflected in the literature review. Those participants whose SOP testing did not experience hardships or issues tended to prefer GembaDocs, whereas those who did were the most sceptical from the group. The study on training impact by Veloso-Besio et al. (2019, p. 258–260) reflects this finding, as those whose testing experience matched the contents of the training, as in their complications being assessable within the scope of the training supplied, could better utilize GembaDocs and develop a positive perception of it, resulting in a more embracing and change-positive organizational climate. In addition, the lowest scored aspects by GembaDocs in the survey, belief of the workforce recognizing the SOPs as their own and useful, based near entirely on the expected resistance to change from the priorly experience-dependent system. These factors are also recognizable in the Lean score dataset analyses, where education and training held great importance to overall Lean performance.

Whereas the workforce was only included in the pilot test in surveying for their SOP format preference, the contrasting values of the recognition dimension reflect as mentioned above resistance to change. Such findings hold value also for L4.0 development systems: for example, the L4.0 MM by Treviño-Elizondo (2023, p. 13–18) noted in their first stage crucial to through workforce communication identify I4.0 challenges and skill gaps, which are sought to solve in the second stage by initiating training programs. Thus, the issues discovered can be perceived as not failures of the examined tool pilotage, but rather now acknowledged skill gaps and challenges in the overall Lean transformation. By extension, since the prior standardization system had little connection to the daily operations at ABB IEC LV Motors Vaasa, the enhanced standardization practices themselves can be perceived as finding such challenges and skill gaps: the G.R.E.A.T. acronym factor Gemba also experienced preference in GembaDocs, thus signifying enhanced operations communication surfacing their issues amidst the Lean transformation.

5 Conclusion and discussion

The last portion of this thesis seeks to generalize the findings in shaping hypotheses as per Eisenhardt (1989, p. 533). The main findings are to be presented from the perspective of the RQs, following with practical implications expressed as suggestions for development at the case company ABB IEC LV Motors Vaasa, the used L4.0 SOP tool GembaDocs, and to future research.

5.1 Conclusion; main hypotheses, answers to RQs

This thesis had two RQs examining the impact of process standardization in context of Lean maturity, the capabilities of its modern innovations, and their possible impacts in context of I4.0 implementations or smart manufacturing. As assessed in the conclusion of the literature review, RQ1 did mostly find an answer within it, but with the whole context of the conducted thesis, the answers to all RQs are as follows.

5.1.1 RQ1: How does standardization affect progressing in Lean 4.0 maturity?

As described in the literature review, the role of standardization in L4.0 maturity development can be assessed from two perspectives: performance and culture. On behalf of performance, standardization supports L4.0 development as a foundational component in enabling changes to the operative system by first stabilizing performance levels and supplying them with predictable base levels with commonizing operating procedures, by such and after which it helps sustain improvements made to operations. For the cultural impact, specifically Lean standardization operates also as a channel for communal contribution to the improvement practices and organizational problem solving, cultivating empowerment and engagement in the workforce as well as a change-positive organizational culture.

Supplementations to this answer can be made from the empiric research of this thesis. Although assessed in the literature review, the roles of education, training and leadership are not only crucial in developing L4.0, but also on behalf of standardization: Lean organizations with successful education programs, recognition of challenges and achievements, and fostering of communal engagement, all of which are achievable with transformational leadership, tend to characterise with higher Lean maturity. Lean standardization is not only subject to this effect but also of aid in achieving it, with sufficient training and motivating to its use working as a diagnostic to identifying challenges recognizing achieved results and sustaining them. By such, Lean standardization, accommodated by education and leadership, also helps the communication of vital factors addressing L4.0 transformations as per the assessed L4.0 MMs.

5.1.2 RQ2: How can modern opportunities improve these effects?

The opportunities in the context of Lean standardization and L4.0 development can be considered as possible I4.0 SOP capabilities deployed to support such initiatives. The main perspective discovered in this thesis was that of the L4.0 SOP tool GembaDocs, whose I4.0 integrations of CPS, AI, and cloud computing streamline the standardization process and provide enhanced capabilities like continuously up-to-date SOPs posting at the point of use, automatic information and content processing, video content inclusion and more. These capabilities make standardization practices substantially easier to perform, thus facilitating their faster upkeep as well as the inclusion of the workforce in the process, enabling above mentioned factors like engagement and recognition, as well as all the ones of the G.R.E.A.T. processes and standardization acronym.

In addition to the standardization process streamlining and culture-building enablement that these capabilities bring, the implementation of such I4.0-integrated tools acts as a vital component conformant of the examined L4.0 MMs: as expressed by Treviño-Elizondo et al. (2023, p. 13–18), early stages of L4.0 transformations should seek to communicate smart technology diagnostic and awareness in preparing for further development. When planning for gradual smart manufacturing integration, PDCA-cycled development plans like that of Bueno et al. (2023, p. 7–12) are to react on the effects of the cycle, like what was experienced in the GembaDocs pilot test. In Lean-emphatic, Lean-first transformations, such Q4.0 system integrations like GembaDocs act thus not only as part of gradual digitalization and smart manufacturing implementation but also create organizational awareness, conversation, and diagnostic of possible challenges, on its part contributing to organizational problem solving.

As noted in the Lean score data, the Gembadocs-connected Lean community has much room for improvement in their continuously improving wasteless organizations. As much as that improvement needs foundation from technical capabilities like standardization, seemingly likewise realized is the necessity of developing people to their utility and achievement. While these capabilities keep changing their operative environments, to adapt and to forerun maintain as matters of culture and its members.

5.2 Discussion

5.2.1 Triangulation and limitations

As per Noble & Heale (2019, p. 67), validity and reliability of research can be proven through four types of triangulation, three of which can be perceived to have been accomplished with this thesis:

- Data triangulation of gathering data from different sources. This thesis was conducted with diverse forms of data, for example time, maturity, and preference measurements.
- Theory triangulation of assessing the information from different theoretical perspectives. Reflexive thematic analysis allowed the cross-analysis of several frameworks, for example the roles of standardization in Lean, I4.0, I5.0 and L5.0 MMs and development systems.

- Methodological triangulation of utilizing several data collection methods. In addition to the broad literature review, data was gathered for example from on-site observations, survey datasets, and expert interviews.

With these considerations, the conducted research can be perceived as valid and trustworthy in its findings. However, also the limitations experienced are to be noted: as mentioned at the start of this thesis, a fundamental limitation of using only a single case company for a case study was mentioned. However, more limitations were found during the conduct of empirical research, with main new limitation found being that of the thesis format and resources, which hindered the research possibilities: for example, the impact of the overall Lean score to the other factors in the GembaDocs datasets could technically be solved to give a more accurate analysis of the inter-factorial relationships, and information regarding the impact over time of GembaDocs implementation at ABB IEC LV Motors Vaasa would have supplemented this thesis' knowledge, an opportunity which the schedule of a thesis work disabled. Due to these limitations, the academic validity of this research is affected, deeming some findings like the quantifiable cultural impact of L4.0 SOPs hypothetical. However, as the findings were examined with these considerations and therefor kept abstract, the research can be considered reliable and of value.

5.2.2 ABB IEC LV Motors Vaasa

Much of what was examined as vital in the literature review, the Lean score data analysis, and the pilot test is already taking place at ABB IEC LV Motors Vaasa: extensive training programs to Lean methods and leadership are underway, found challenges are being assessed, and the new standardization system is under construction in high accordance to the beneficiary factors examined in this thesis. In accordance with the general public of the Lean score survey respondents and the preferred approach of this thesis, this Lean transformation is being led with a change to the people and grounded with operations stabilization, rather than overstepping into Lean manufacturing methods known to produce failures without sufficient foundation. From a general perspective guided by the knowledge of this thesis, the ABB IEC LV Motors Vaasa Lean transformation is developing as per a likely successful approach.

However, some suggestions can be made to supplement this digitalizing Lean initiative based on the findings of this thesis, mainly from the perspective of adding process definition and capabilities over the duration of Lean development. For example, although the 2SL approach is an effective initiator and driver to a problem-solving Lean culture, the planned eventual implementations of highly data-driven smart manufacturing would benefit of higher data integration of what is typical with 2SL organizations, who as per associated literature denounce KPI overdependence. Such further implementations of data collection and utilization should however be done gradually, as per was assessed in the suggested development approach of implementing Lean first along gradual Q4.0 integrations, who in addition to assisting the Lean transformation create presence, awareness and communication of I4.0 capabilities. Raising Lean process definition and capabilities to growing data utilization, for example through methods like LSS, should as per Torkkola (2018, pp. 72–78) be introduced only after initial chaos has been organized and stabilized, where necessary foundation for operations changes has been accomplished.

By extension, such data collection and utilization supports readiness of I4.0 implementations as per models like that of Schumacher, Erol & Sinh (2016, p. 164), as well as having Lean implemented first altogether prevents the transformation of wasteful activities to smart manufacturing as per Komkowski et al. (2025, p. 608). As an example of growing such process definition and capabilities, takt time, walking time, or cycle times could be included into the SOPs to more resemble the standardized work by Liker & Meier (2006, p. 126), staying on time in which could be measured with the MES checklist integrations, and eventually be included for example to digital twin systems for operations simulation, disruptions analysis, and I5.0-accordant system assistance in decision making. The main point to be made based on this thesis however maintains as adding process definition and capabilities only gradually, developing systems on established knowledge and capabilities.

5.2.3 GembaDocs

As for the technical issues found in the pilot test, for example automation malfunctions, are self-evident factors for development, can additional capabilities be suggested. As assessed, the intended utilization contexts and purposes between GembaDocs and the Liker & Meier (2006, pp. 111–127) are different. However, as mentioned above as a possibility to developing operations definition and capabilities, more descriptive information like walking times and takt times could help both in identifying operational waste, optimize system towards external demand scheduling, and develop I5.0 accordant systems. Although GembaDocs is based in the 2SL approach of developing people and culture while discouraging overdependence to process metrics, the rampant digitalization of business environments which the tool itself takes part of is to be noted and considered as a factor of development. In this perspective of 2SL human centricity, the preferences in formatting experienced in the pilot test should also be noted. In addition, the I4.0 integrations could have further development potential: for example, since the video function already has AI-assisted video editing capabilities, such AI could technically be trained in identifying operational value and waste in the pictured activities, enhancing pure value delivery and improvement capabilities.

Some additional ideas for development were also discovered during the conduct of this thesis. To start, although GembaDocs does provide alternatives to the posting of the SOPs in both whole printed form or the QR-only form, the whole printed form does typically not include a QR-code to the digital version but rather to a feedback system, which technically enables expired versions of SOPs being posted at the point of use. Another point was found in the ISO-accordant document identification codes, currently in only a sequence number format: in elsewhere located ISO9001 IMSs, the document codes could technically overlap between GembaDocs and the IMS, voiding the practicality of the codes in the tool. Thus, definition to the SOP identification codes could be beneficial, for example with differentiating prefixes. For the final suggestion, although the Kamishibai function of GembaDocs was not assessed in this thesis, its digital integrations in for example traceability of completed tasks seemed limited, with potential for development.

5.3 Further research

Like repeatedly expressed, gaps in research are plentiful regarding Lean standardization and modern SOP practices in general. However, as displayed in this thesis, the used methods are undergoing significant changes, with growingly deeper system integrations conformant of modern smart manufacturing systems with vital importance within their development. Based on the findings, future research to not only the developing standardization methods is in place, but also to their role in their modern and digital utilization environments.

In addition, current L4.0 development models represent only balanced Lean-I4.0 developments happening simultaneously. Since the possibility of realization to such comprehensive operational overhauls can be in smaller companies questionable, gradual, or one-subject-area-first approaches should be explored.

Due to the still immature research field regarding L5.0 development having little representation, research to such ends ought to be pursued as well.

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Appendices

Appendix 1. The GembaDocs pilot test survey

The survey had three forms of questions: four questions with free-formatted portions to measure task durations, one question with a free-formatted portion for open feedback, and --- questions with a modified Likert scale for assessment of the G.R.E.A.T. acronym's factors, where to every question the selectable values of one to five signified the following:

1. Prior SOP system totally better
2. Prior SOP system preferrable
3. Equal delivery / no preference
4. GembaDocs preferrable
5. GembaDocs totally better

The questions were as follows:

1. How long did it take for you to create your SOP with the prior system?
2. How long did it take for you to modify your SOP with the prior system?
3. How long did it take for you to create your SOP with GembaDocs?
4. How long did it take for you to modify your SOP with GembaDocs?
5. G – Gemba: Which alternative reflected more the practical knowledge and understanding of the process described which is needed at the point of use of the instruction?
6. R – Recognized (1/2): Which alternative would be easier for users of the SOP to recognize as their own and as useful?
7. R – Recognized (2/2): Which alternative would be easier in including its users in the process of creating or updating the SOP?
8. E – Easy (1/3): Which alternative was easier to create?
9. E – Easy (2/3): Which alternative was easier to modify?
10. E – Easy (3/3): Which alternative could be easier to approve and publish?

11. A – Available at the point of use: Which alternative could be more sufficiently available at the point of use, “on the front line”?
12. T – Tested & trained: Which alternative would be easier to test before deployment and train on its content?
13. General picture (1/2): Which alternative was easier to use overall?
14. General picture (1/2): Which alternative presented more challenges?
15. Open feedback

Participants of the pilot test were quality managers, quality engineers, and product engineers.