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Preface

It is becoming increasingly difficult for high-wage countries to maintain living standards. There is the inevitable globalization, an aging population and the lack of skilled workers. It is therefore no coincidence that greater efficiency and effectiveness is called for in production and administration. The ineffective use of resources and inefficient processes lead to unnecessary costs, loss of time, overproduction or errors. Many organizations are trying to solve the challenges with new (digital) technologies. They overlook the fact that a technology is only as good as its application. Otherwise, the supposed solution creates new digital waste. The key to more efficient and effective processes lies in process design. This is exactly where lean management comes into play.

Against this background, the Professorship of Factory Planning and Intralogistics organized the 10th European Lean Educator Conference (ELEC). The high-profile conference brought together leading lean management experts that aim at making processes better and possibly cheaper. The focus is on the latest insights from practice, and the exchange of experiences within science as well as between academic institutions, industry and public services. ELEC 2024 took place from September 25th to 27th 2024 at Chemnitz University of Technology. An industry tour and social events rounded off the official program, consisting of keynotes, sessions and workshops.

ELEC is the first time in East Germany, which experienced specific challenges and disruptions, but also hopes and new futures. The ore mountains are a traditional industrial region, being it argued that the first textbook on operations management was written on the mining industry in this region. Mining always brought its own challenges in terms of sustainability, quality of work life and process efficiency, but also major technological advancements and highly skilled labor. Many of the papers presented at ELEC address similar challenges than 500 years ago. The problems did not change but are more volatile, uncertain, complex, and ambiguous today given the interconnectedness of society and production. Conferences such as ELEC, are a key ingredient to successfully solve and manage these problems.

The ELEC 2024 program shows that ELEC still can make and will continue to make a significant contribution to management disciplines. In 2024, 16 contributions were selected for inclusion in the conference proceedings from a total of 19 submissions. The ELEC 2024 conference proceedings are organized into one volume, covering a large spectrum of research addressing the overall topic of the conference “Lean Practice for a Better Future”. This includes: lean 4.0, lean healthcare and services, lean applications, and advances to lean theory. We would like to thank all contributing authors for their high-quality research work and their willingness to share their findings with the ELEC community. We are equally grateful for the outstanding work of all the International Reviewers and the Program Committee Members.

September 2024
Matthias Thürer, Christoph Roser, and Constantin May
Conference Co-Chairs

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Lean Education

Exploring the role of learning factories in fostering student creativity: An investigation into lean education

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1 Introduction

Learning factories are pedagogical and research platforms that enable new approaches to knowledge transfer for both students and professionals (Abele et al, 2019; Gento et al, 2020). As a result of the collaboration between universities and companies, the first learning factories appeared in Germany in the 1980s and then in the United States in 1994 (Abele et al, 2017). In France, the first learning factory appeared in Lyon in 2009. The concept was democratized following the government's Dorison report (Ballé et al, 2021). These learning factories promote education, research and innovation (Tisch and Metternich, 2017) based on constructivist learning theory (Abele et al, 2017) and experiential learning (Garay-Rondero et al, 2019). These learning factories have subsequently given rise to contextualized research work (Zancul et al, 2022) by highlighting organizational dysfunctions that need to be resolved. In our case, we focused on pedagogical aspects, especially in the context of transferring lean management practices (Choomlucksana and Doolen, 2016; Meissner et al, 2018). We studied non-technical competences, especially creativity (Aulia, 2023), adopting an approach oriented towards competence development (Tisch et al, 2016). In fact, most of the competencies examined in previous research are rather technical competencies in the field of operations management and industrial systems (Baena et al, 2017).

In the realm of management science, creativity and innovation are closely intertwined yet represent distinct processes. Creativity is characterized by the ability to generate novel ideas adapted to specific contexts (Bonnardel, 2009), whereas innovation pertains to the subsequent implementation of these ideas (Anderson, 2014). Within the domain of lean management, the focus has predominantly been on innovation, particularly through the lens of efficiency, as evidenced by existing literature (Belfanti, 2019; Browning & Sanders, 2012; Choomlucksana & Doolen, 2017; Lins et al., 2021; Möldner et al., 2020; Solaimani et al., 2019; Tisch & Metternich, 2017). Some research managed to depict the soft practices and competencies that can help lean and innovation (Solaimani et al, 2019). However, this emphasis on innovation fails to capture the entirety of the creative process within lean management, neglecting aspects such as the generation of new ideas and the impact of creativity on individual learning. Employee behaviors related to creativity appear to be critical to bridging lean and innovation, even though these behaviors cannot be separated from the operating system (Jaffre, 2024). Creativity represents the first step to adopt innovative behaviors in the workplace. Our hypothesis is that learning situations created in learning factories, based on experiential problem-solving approaches, can enable participants to enable creativity competencies.

This research aims to illustrate the famous motto “Creativity before Capital” by answering the following research question: how do learning factories, through lean education, help develop creativity in participants?

2 Methodology

Using literature as a starting point, we will explore forms of creativity that can emerge in a learning factory. We believe that learning situations created in these learning factories, based on experiential problem solving approaches, can enable students to mobilize innovation and creativity competencies. Our epistemological approach will be a case study approach (Yin, 2018), as we will explore this aspect through lean management learning.

To explore the forms of creativity that can emerge in learning factories, we studied a teaching sequence based on lean management learning that lasts for three days. We conducted a first exploratory study with groups of third-year engineering students. The sequence focused on teaching the main theories of lean management (quality, value versus time, problem-solving methods, flow efficiency vs resource efficiency, introduction to the kanban method), alternating theoretical and practical parts with the learning factory. First of all, as a preliminary study, we observed a group of students, collected observational notes (16 pages) and took pictures/videos of the artifacts they used/constructed (33) in 2023.

From this study based on observations, we analyzed the data through forms of creativity. We mobilized Nvivo software to identify two aspects of creativity (impact and creativity process, defined as a micro-process). We identified the impact of creativity based on these four categories:

- High-C Creativity: This level of creativity, often referred to as "Big-C creativity," involves groundbreaking innovations that significantly impact society (Csikszentmihalyi & Csikszentmihalyi, 1988; Davis et al., 2011; Kaufman & Beghetto, 2009).
- Medium-C Creativity: it entails the generation of new strategies or alternative approaches to problem-solving (Moran, 2010). These innovative strategies aim to address existing challenges more effectively.
- Low-C Creativity: also known as "Little-C creativity," it encompasses extraordinary actions within an individual's daily environment (Craft, 2000). These acts may not have far-reaching societal implications but are notable within the individual's immediate context.
- Mini-C Creativity: it involves the novel and personally meaningful interpretation of experiences, actions, and events (Kaufmann & Beghetto, 2009). This form of creativity emphasizes the dynamic and interpretive process of constructing personal knowledge and understanding within a specific sociocultural context.

To analyze the creativity process, we used the following categories:

- Convergent thinking: it allows us to focus on a single idea (Guilford, 1950), reducing the set of possible ideas to a single one, thus leading to the provision of a right or wrong answer (Chermahini & Hommel, 2012). It would make it possible to assess the quality of ideas in relation to the constraints of the task (Jaarsveld, Lachmann & van Leeuwen, 2012).

- Divergent thinking: the ability to generate a wide variety of ideas (Runco, 1991)
- Associative thinking: combination of two seemingly independent elements.

Data were classified in these categories when they corresponded to the definition. To illustrate, the note "He puts tape on the fridge to get an indicator" was categorized as part of sections “Mini-c creativity” and “Convergent thinking”. This classification is justified by the fact that this action refers to an individual action and interpretation by the student in this learning context. It introduces a new idea and enhances an artifact within the learning context. This action also focuses on a single idea that addresses a specific problem.

During May 2024, we conducted a second study including both a student group (15) and a professional group (8). Our aim was to measure pre- and post-training variables within the learning factory environment. Specifically, we focused on two sets of variables: those related to the dimensions of engagement, drawing from Schaufeli and Bakker's seminal work (2003; 2006) (Table 1), and those associated with creativity support, inspired by Cherry and Tulipe's research (2014) (Table 2). Engagement dimensions were measured with a 6-point Likert scale once before the training; Creativity support was measured with a 10-point Likert scale before and after the training. We also participated in the training and took pictures/videos (14) of the artifacts constructed by the students/professionals. The pictures and videos helped us gather qualitative data on the evolution of creativity from the participants (Walker and Boyer, 2018). Additionally, they are regarded as instructional artifacts (Martinez et al., 2012) due to their generation within a training context. They can be used to measure various features of instructional practice.

Table 1: Engagement survey (Schaufeli et Bakker, 2003; 2006)

Scale	Questions
Vigor	1. At my work, I feel bursting with energy (VI1)
Dedication	2. I find the work that I do full of meaning and purpose (DE1)
Absorption	3. Time flies when I am working. (AB1)
Vigor	4. At my job, I feel strong and vigorous (VI2)
Dedication	5. I am enthusiastic about my job. (DE2)
Absorption	6. When I am working, I forget everything else around me. (AB2)
Dedication	7. My job inspires me (DE3)
Vigor	8. When I get up in the morning, I feel like going to work (VI3)
Absorption	9. I feel happy when I am working intensely (AB3)
Dedication	10. I am proud of the work that I do (DE4)
Absorption	11. I am immersed in my work (AB4)
Vigor	12. I can continue working for very long periods at a time. (VI4)
Dedication	13. To me, my job is challenging. (DE5)
Absorption	14. I get carried away when I am working (AB5)
Vigor	15. At my job, I am very resilient, mentally. (VI5)
Absorption	16. It is difficult to detach myself from my job. (AB6)
Vigor	17. At my work, I always persevere, even when things do not go well. (VI6)

Table 2: Creativity Support Survey (Cherry and Tulipe, 2014; Carroll et al, 2009)

Scale	Questions
Collaboration	1. The system or tool allowed other people to work with me easily.
	2. It was really easy to share ideas and designs with other people inside this system or tool.
Enjoyment	1. I would be happy to use this system or tool on a regular basis.
	2. I enjoyed using the system or tool.
Exploration	1. It was easy for me to explore many different ideas, options, designs, or outcomes, using this system or tool.
	2. The system or tool was helpful in allowing me to track different ideas, outcomes, or possibilities.
Expressiveness	1. I was able to be very creative while doing the activity inside this system or tool.
	2. The system or tool allowed me to be very expressive.
Immersion	1. My attention was fully tuned to the activity, and I forgot about the system or tool that I was using.
	2. I became so absorbed in the activity that I forgot about the system or tool that I was using.
Results Worth Effort	1. I was satisfied with what I got out of the system or tool.
	2. What I was able to produce was worth the effort I had to exert to produce it.

3 Results

3.1 First study

The preliminary study during the three days training revealed the following results. After coding, creativity is identified after the first day of the learning sequence. For the category "impact of creativity", 15 out of 17 classified data are on the second and third day. For the category "process of creativity" it is 12 out of 15. This result is due to students' growing familiarity with lean theories and hands-on experience gained within the learning factory environment. There is also a notable prevalence of convergent thinking (14) and mini-creativity (10). These results reflect students' focus on problem-solving, particularly in optimizing production lines. Students leave no room for exploration or creativity in finding solutions. However, the problem-solving focus of the learning context and the optimization-focused instructions from teachers may limit the development of divergent thinking skills. It led students to mainly practice mini-creativity, which is particularly important in the learning context (Bjørner et al., 2012). Moreover, mini-creativity is predominantly individual (7) rather than collective (3). The same applies to convergent creativity, with five references to the individual as opposed to nine for the collective. In this context of discovering lean management, students may find it difficult to practice creativity collectively. This is paradoxical as they are organizing themselves to improve productivity using organizational tools. This goes back to the previous comment where the students' priority is to solve problems.

3.2 Engagement level

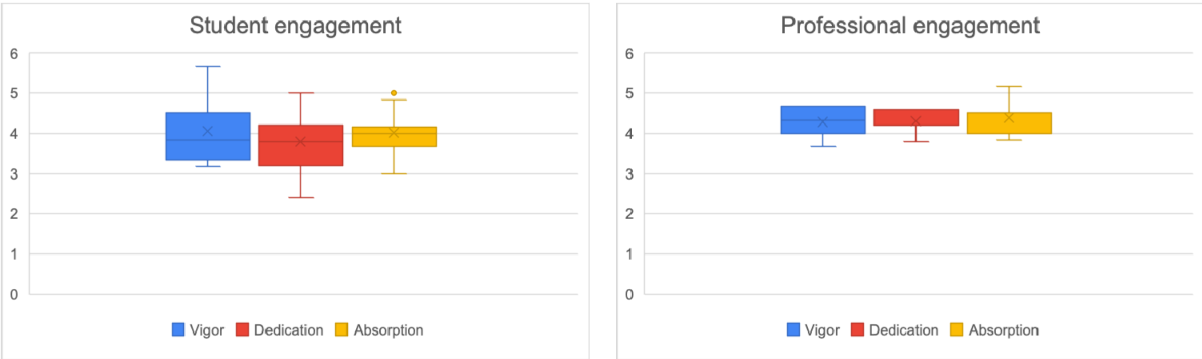

Figure 1: Engagement level of the two groups

We analyzed the engagement based on 3 dimensions: vigor, dedication and absorption. The results show that the level of engagement is high (a mean of 4 at least of both groups) with a slightly higher engagement and low dispersion from the professional group. Interestingly enough, student engagement, especially through vigor and dedication, seems to be more variable for students than professionals. This level of engagement can be explained by the simple action of answering the questionnaire. The participants that filled the questionnaire represented 62% of the students and 57% for the professionals that participated in the training. We can assume that the participants that answered were the ones interested in the research activity and in the training, so that could explain why there is a high level of engagement in the following tasks. Although, the difference in engagement level between students and professionals can be explained by the simple fact that professionals chose to follow this specific training to develop their lean competencies. This can show the differences between intrinsic motivation (professionals) and extrinsic motivation (students) and its impact on engagement level (Ryan and Deci, 2000).

3.3 Creativity support

We analyzed creativity support based on six dimensions: collaboration, enjoyment, exploration, expressiveness, immersion, and results worth the effort. The data related to these dimensions before and after the training/class in the learning factory are presented in the following table, considering the overall population, student population, and professional population:

Table 3: Data related to creativity support from the second study

	Global comparison				Students comparison				Professional comparison			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
Collaboration	0,79	1,00	0,00	-0,26	0,70	2,00	0,00	-0,71	0,33	-0,50	0,00	0,10
Enjoyment	-0,58	0,00	-0,50	0,18	-1,30	0,00	-2,50	-0,40	-0,25	-0,50	0,00	0,21
Exploration	-0,04	0,50	0,50	0,12	-0,30	1,50	-0,50	-0,38	-0,15	-1,00	0,50	0,33
Expressive-ness	-0,64	-0,50	0,50	0,67	-1,05	0,00	1,00	0,44	-0,48	-2,00	0,50	0,78
Immersion	-0,78	-1,50	-1,00	0,18	-1,06	-1,50	-1,50	0,24	-0,18	-1,00	0,00	0,11
Results worth effort	1,27	2,00	-1,00	-0,70	0,89	2,00	-2,50	-1,27	2,10	1,00	2,50	0,56

To compare the results obtained, we decided to display only the differences in the values of the mean, minimum, maximum, and standard deviation before and after the training/class in the learning factory. The following table presents the results of this comparison: positive values indicate a gain after the training compared to before, while negative values indicate a loss after the training compared to before.

Based on the comparison results, we can see that the learning factory fosters “collaboration” and “results worth effort” with an improvement of the mean for both groups. Standard deviation related to those two dimensions is improved for professionals and decreased for students. “Collaboration” and “results worth effort” are the two dimensions where the differences before and after the training are statistically significant ($p<0,05$). The improvement in the "results worth effort" category can be explained by the learning context and lean education itself. In fact, participants have to be efficient and achieve better results in order to improve the production line. So when they get results, they have a sense of satisfaction that makes their efforts worthwhile. Moreover, lean education puts emphasis on collaborative interaction in teams. All those aspects about collaborative interaction were experimented during the training and participants could see the benefits of these new interactions.

The decrease in students' standard deviation related to “results worth effort” can be attributed to their performance during the training. Unlike professionals, students quickly achieved better performance results, making the tasks less rewarding as they were more easily attainable. Two main factors can explain the decrease in students’ standard deviation related to “collaboration”. First, the time allocated for interaction and collaboration is predefined, thus limiting its impact. Second, the student population is homogeneous, as they are all engineering graduate students of the same age and with similar reasoning abilities. This homogeneity reduces the need for interaction and collaboration compared to the professional population.

Both "expressiveness" and "immersion" have decreased in terms of mean values, but the standard deviation for both groups has improved. Regarding "expressiveness," a few participants took on greater leadership roles, which led to increased expressiveness for them. However, the majority were less expressive than expected, likely because they allowed the leaders to take charge. For "immersion," there was a notable decrease, particularly among students during the training. This can be attributed to the initial novelty of the learning factory wearing off, leading to a more detached behavior among some participants as tasks were managed collectively by the group.

Both "enjoyment" and "exploration" have decreased in terms of mean values, but the standard deviation has improved only for professionals. The decrease in “enjoyment” could be attributed to the phrasing of the questions. The questions used common terms like system and tools, which participants may have confused with those related to lean education rather than creativity in the learning factory. The decrease in "exploration" was slight, making it difficult to interpret the results definitively. However, it suggests that the learning factory did not significantly enhance the exploratory aspects of creativity, which is somewhat counterintuitive given previous literature on the subject. We can also assume that the learning factory or its usage condition was not optimal enough regarding its natural features, but it can help reduce the variability inside groups. Those results can depend on the learning factory environment, the training content, how we bring the content (pedagogical sequence), and the trainer personality/directives.

3.4 Pictures analysis

The two groups mostly used whiteboards and paperboards available in the learning factory. They used it to depict the layout/organization of the learning factory, planning preparation, and activity monitoring. There is some variability in the information displayed and common ground too (organization representation, quality and service KPI selection, main concerns, problem-solving). Some students decided to use digital tools on their own especially for planning and monitoring activity. According to them, it gives them more flexibility to change parameters while collaborating together.

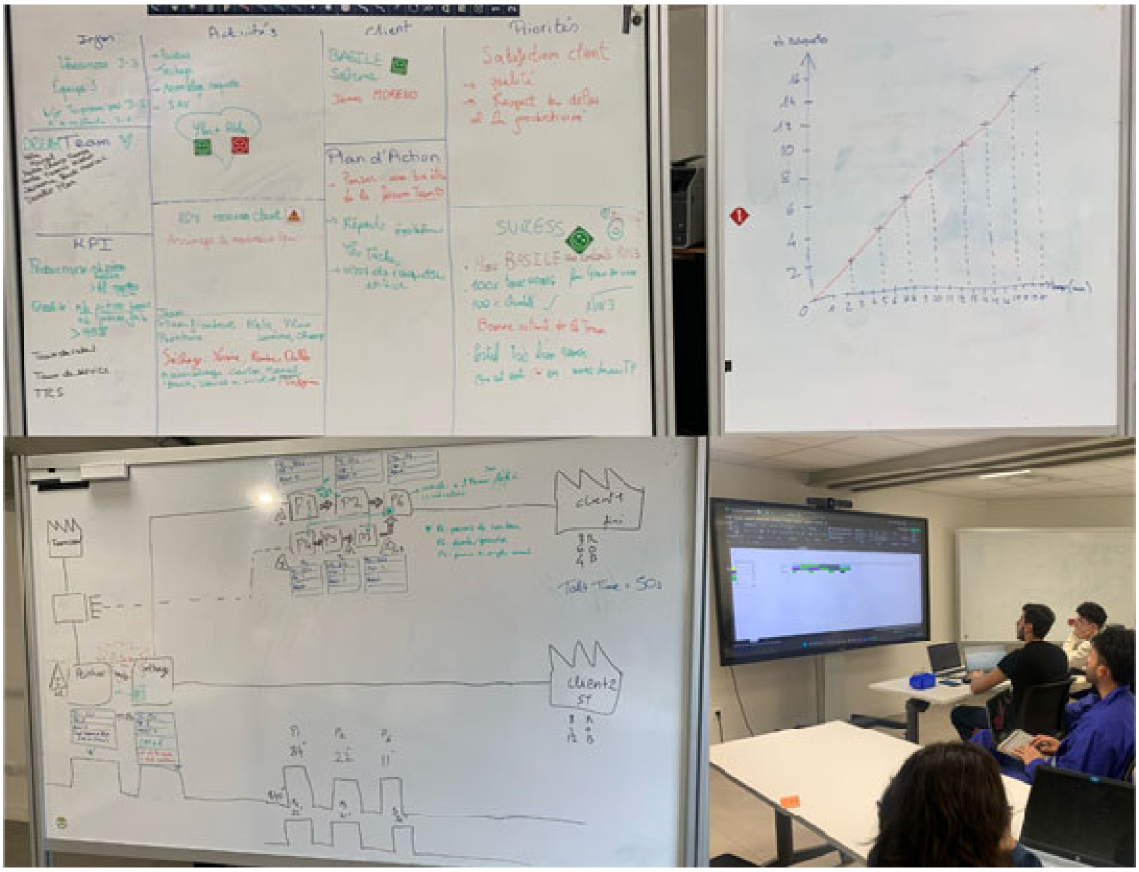

Figure 2: Display of creativity support (pictures taken during the training)

Data is currently being analyzed. A more extended study will be executed starting in September 2024 to have a more representative sample of students and professionals and better appreciate cluster groups of participants based on their level of engagement.

4 Conclusion

This article presents an analysis between learning factory and creativity support. The relation was moderated through the high engagement level of participants. Surprisingly, only two dimensions of creativity support were improved during the training: “collaboration” and “results worth effort”. The main limitations of the current study are related to the size of the sample, the wording of the creativity support questionnaire and the non-controlled variables related to the training (duration, trainer personality or directives). This article represents the first steps of a more important study. Anchored on these initial results, we will conduct further data collection with groups of students (150) following the same type of teaching sequences during the following months.

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Serious Game: VR real-time simulation of a value stream analysis

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Abstract

Virtual and mixed reality technology (VR) is one of the key technologies of industrial digital transformation. Thanks to the powerful immersive hardware systems available, virtual reality (VR) technology enables complete immersion in the VR world and realtime interaction with the objects contained in the VR environment without restriction. By using VR technology, complex and large-scale industrial systems and processes (e.g. production and logistics processes) can be presented adequately and tangibly, even for non-experts. This enables users to fully immerse themselves in the virtual environment and to view and interact with the virtual objects without major restrictions. However, the potential of VR to digitize and improve the engineering process in industrial companies, especially SMEs, is still undiscovered. This has resulted in VR applications in engineering being insufficiently implemented and utilized compared to other industries, such as gaming and entertainment. In this work, the potential of VR for the realistic visualization and simulation of industrial processes was investigated by developing the visTOC approach.

1 Serious Games in the industry

While simulated VR environments are suitable preparation for real, work-integrated practice (Dlamini, 2023), real learning about how an industrial environment works and behaves takes place through repeated engagement with the VR world (Allcoat & von Mühlenen, 2018). However, repeated participation or engagement with a virtual environment requires activity-based motivation (Rheinberg & Engeser, 2018). The addition of well-designed gameplay to a VR simulation leads to an anticipation of fun that fosters the kind of motivation that brings users back to regular engagement in a virtual environment (Makransky, 2019). Serious games take the mechanics and dynamics that make digital entertainment games so popular and apply them to simulation-based training.

In manufacturing, serious games can simulate production lines and allow users to understand workflows, identify bottlenecks and test solutions to improve efficiency (Leitao, 2021). These simulations often include elements such as resource allocation, machine operation and supply chain management, providing a holistic view of the industrial ecosystem (Faisal, 2022). Five of the most well-known serious game examples of key players in the industrial landscape are: (a) The Beer Distribution Game developed by MIT simulates a supply chain scenario where players take on the roles of retailers, wholesalers, distributors or factories. It is designed to show how small fluctuations in demand can lead to significant fluctuations in the supply chain; (b) INNOV8 from IBM is a 3D simulation game for business process management (BPM). It is designed to help users understand process optimization and the impact of decisions on business performance; (c) Plantville from Siemens also simulates the management of a production plant. Players are tasked with maintaining the operations of a plant, focusing on aspects such as productivity, efficiency and sustainability to illustrate the importance of strategic planning; and (d) SimPort-MV2, a serious game developed for the Port of Rotterdam Authority. It simulates the planning and development of the port expansion project Maasvlakte 2. By asking players to balance economic, environmental and social factors in order to successfully develop the port, this game illustrates the complexity of large-scale industrial projects and the importance of multi-criteria decision making.

Considering that these serious games are praised by users for their educational value and are widely used both in universities and companies for internal training, there is no doubt that these examples highlight the potential of serious games for industrial systems simulation. However, all of the above examples are played on a standalone PC or web-based platform and have no specific application for SMEs. Our paper aims to explore the potential user experience benefits of a more complete immersion in a VR serious game to convey the intricacies of industrial systems and processes for smaller factory operations.

2 Programming a serious game as an intercultural and international didactic concept (meta-level)

The programming was carried out by a trinational project team of five students using the Unity programming software, with the project workshops taking place alternately at the universities in Finland, Tunisia and Germany. Different study programs

- Turku (FIN) = Gaming Lab
- Sfax (TUN) = Multimedia, User Interface and User Experience
- Karlsruhe (GER) = Mechanical Engineering and Lean

in an intercultural context support the exchange of learning and experience. By explaining the required LEAN principles of the German students to the programmers in the team, the LEAN knowledge of the LEAN educators was consolidated and expanded on the one hand, and on the other hand the principles could be abstracted in the programming view and thus specialist knowledge could be transferred to the other disciplines. This process was coached by the supervising professor.

The VR implementation makes it possible to adopt different perspectives in the serious game during play:

- The perspective from the point of view of the employee (frog perspective) at a machine is limited here, the material flow and dependencies cannot be overlooked. This corresponds to the classic shop floor employee.

- The perspective from the top floor (bird's eye view) provides an overview of the entire hall or the scenario of the entire production line.

This means that the perspective of an employee, a manager or anything in between can be taken, which can be used to compare the “horizons of experience”.

Several game sequences have already been implemented experimentally in the virtual factory (Figure 1)

- Visualization of cycle changes in synchronous production (metronomes)
- Visualization of bottlenecks
- Visualization of value streams
- visTOC (visualization of bottlenecks according to the Theory of Constraints) using two Heijunka lines (serious game)

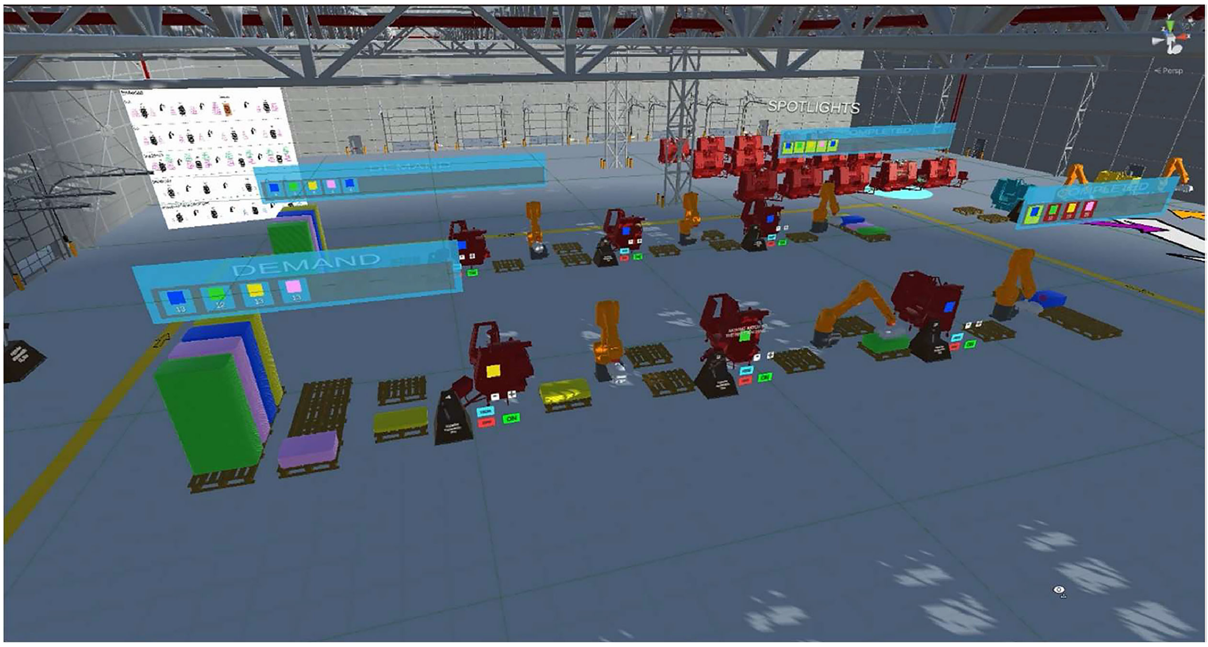

Figure 1: Bird's eye view of the virtual factory

The VR-based production simulation tool immerses users in a virtual production environment and illustrates the intricacies and challenges of real production processes. By providing a detailed and interactive interface, users can change various parameters to optimize lead times and gain insights into potential bottlenecks and improvements. In particular, the ability to use a time-lapse feature allows the game sequences to be sped up and go into slow motion at particularly interesting points.

3 LEAN-Basics for the Serious Game „visTOC“

Lean production, also known as lean manufacturing or simply lean, is a highly efficient world of production methods that aims to maximize the value creation process while minimizing waste. The central idea behind lean is the pursuit of continuous improvement to reduce waste and increase quality and efficiency. This requires a comprehensive change process that includes a critical review and scrutiny of existing processes. Through continuous analysis and optimization of workflows, bottlenecks are identified and eliminated, workflows are streamlined and a culture of continuous improvement is promoted.

In order to be able to fulfill customer requirements flexibly and effectively, it is necessary to systematically reduce batch sizes. This usually leads to more frequent changeovers. To ensure that the entire production system remains efficient, it is important to keep set-up processes as short as possible. This is where the SMED method can be helpful.

This method aims to reduce waste through organizational and technical measures in order to shorten production and set-up times and increase the efficiency of the overall system. The concept of reducing set-up time and minimizing waste of any kind originates from the Toyota Production System. The aim of SMED is to reduce throughput time through smaller batch sizes, speed up the process and optimize productivity.

The customer-oriented production system, the pull system, is an approach to production and supply chain planning that is based on actual demand. In contrast to the push system, in which products are manufactured on the basis of forecasts and pre-planned requirements, the pull system only triggers the production and provision of products when there is actual demand. (Mathiyazhagan, 2021) The advantage of a pull system is that it aligns production planning and control with actual demand, which can lead to less excess inventory, shorter lead times and lower inventory costs. It also enables more agile and responsive production as it responds directly to market needs. (Pepels, 2015, Roser, 2021)

The bottleneck is a part of the production process that determines and, above all, limits output, productivity and maximum capacity. (Goldratt, 2004)

Fluctuating quantities generate inventories (Mura leads to Muda). Bottleneck situations occur both at machines and at employees' workstations. While bottlenecks on assembly lines become visible at an early stage by stopping the production line, the problems in autonomous individual systems are hidden and not easy to recognize. Bottlenecks can be caused by cycle times that are too long or by unstable machines and process fluctuations. These fluctuations can be caused by machine cycle times, quality problems or malfunctions and machine failures. The aim is to optimize or eliminate the bottleneck. Further improvements to other production processes are not effective as long as the bottleneck remains. (Bertagnolli, 2018)

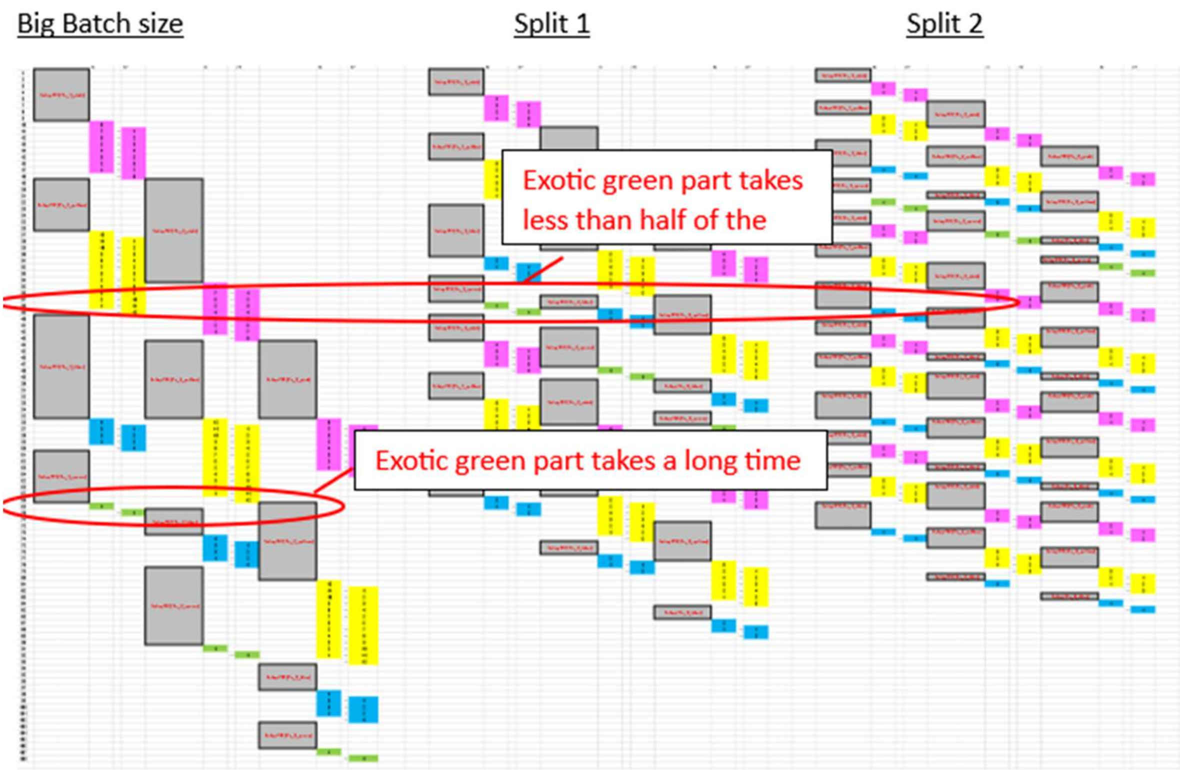

Figure 2: Batch size calculation concept

As Figure 2 shows, the batch size in conjunction with the set-up time has an influence on the time that a Z product (exotic product) needs to pass through production. The left column shows long set-up times and a large batch size. In this example, an exotic product would require around 70-time units. If both the batch size and the set-up time are halved, the exotic product requires only about half the processing time. If this idea is taken further, the experiment ends with all products and especially the exotic product being available many time units faster. This intervention in the set-up times and batch sizes means that Z-deliveries in particular can be better fulfilled as the waiting times are reduced.

4 Project visTOV and implementation

The virtual production hall is modeled on a real production environment and offers a realistic environment in which the user can observe and help shape the production process. At the beginning, the user sets the initial production parameters and thus simulates the start of a production run. The user interface (UI) is arranged vertically in the VR hall and can be controlled with a joystick. Via this interface, users can set the setup time (tr) and execution time (te) for each machine and product. These settings can be made at any time directly on the machine or via a central control panel, allowing flexibility and control over the production process.

Product management in this VR system is user-friendly and efficient. The user can add products via buttons on the left-hand side of the user interface. By clicking on a product, the user can change its type, which is indicated by a color change. The total quantity of each product is always visible in the top left corner, allowing the user to easily monitor stock levels.

Machine management is similarly simple: using the plus and minus buttons, the user can add machines in increments of one, ten or one hundred. Once all parameters are set, the “Send” button triggers production and the machines start working automatically. A split button in Figure 3 allows the user to split the batch quantities and sizes multiple times by a user-defined factor for the second production line, further increasing production flexibility (Heijunka).

Figure 3: Control board

Key Performance Indicators (KPI) charts are an essential part of the control panel. These charts show the correlation between the time required to manufacture a product and the combined setup and production time. By comparing different lines, users can see the effects of changes in machine parameters such as batch sizes and processing times. It becomes clear that smaller batch sizes with very short set-up times are much more efficient as customers receive their parts faster. This is particularly beneficial for exotic products that would otherwise take a long time to produce due to having to wait for other product batches to be completed. The order of product batches, which is determined by customer demand, remains unchanged, so the only way to speed up the process is to split the size and increase the quantity to create smaller batches.

The application shows how important it is to understand how a long set-up time can hinder efficient production. Although it may seem difficult to reduce set-up times, there is always room for improvement. For example, changing a tire on a car takes hours in a garage alone, whereas a good mechanic can do it in less than fifteen minutes. Formula 1 mechanics only need a few seconds. The aim is to reduce the set-up time of a machine in a similar way. Separate KPI charts for each production line distinguish between the sum of te and tr and, in another chart, the sum of tr with te multiplied by the batch splitting factor.

The value stream analysis (VSA) is an important tool for recording key production figures. The VSA display has been adapted for visTOC. Each machine is shown with a number, whereby a maximum of five machines per line are possible. The lower bar shows the production time, i.e. the time that a product effectively spends in a machine, while the upper bar shows the set-up time for each machine. Each bar adapts individually to the data entered in the control panel. It becomes clear how long a product spends in a machine and how long it is maintained by machine set-up. Ideally, the machines should be SMED-capable (Single Minute Exchange Of Dies) and have a setup time of just one minute in order to minimize the set-up time in relation to the production time. Higher batch split factors and shorter set-up times reduce the overall production time.

Two lines, each with four machines, are set up in the production hall. At the front, a stack with four different product colors simulates the panels to be processed. The products selected by the control panel are placed on the first pallet to simulate their arrival from the warehouse. Each machine has pallets on both sides for the material produced. The robots positioned between the pallets lift the batches onto the pallet of the next machine. These machines, pallets and robots are derived from templates and are freely available in the simulation. Buttons for lines A and B allow side-by-side display and comparison, demonstrating the efficiency of frequent, quick adjustments.

Figure 4: Production hall inside: the heijunka lines

In the production hall in Figure 4, line A is located at the front and line B at the back. Both lines can be adapted with additional machines. Orange robots between the individual machines automatically transport the batches from one pallet to the next and visualize bottlenecks when a robot can no longer find a free space. Each product color is easy to distinguish, and when an ordered quantity is ready, the red frame of the last pallet turns green and a corresponding chime sounds. Each row has its own chime to avoid confusion. The “COMPLETED” indicator quickly shows which line can produce faster, allowing an immediate assessment of production efficiency.

By utilizing VR technology, users can experiment with different production parameters in a risk-free environment and experience the impact of their adjustments on overall production efficiency as well as cycle, flow and impact on cycle time. This simulation serves as an advanced tool for training and optimizing manufacturing processes and highlights the importance of reducing setup times, managing batch sizes and improving overall production flow.

5 Options for expanding the application

Automatic detection of bottlenecks: There is considerable potential for improvement in the implementation of automatic bottleneck detection in the forecast as well. This function could be programmed so that the machines automatically give a signal as soon as they cause or will cause a bottleneck. This bottleneck detection should be designed variably depending on the set-up times and batch sizes in order to be able to realistically map different production scenarios.

Expansion of material simulation: Another useful expansion concerns material simulation. Currently, the material is moved automatically between the machines by robots. In the extended version, the material is to be picked up by a forklift truck both before and after the machines and transported to the corresponding storage locations. This would make the simulation more realistic and better reflect the logistical challenges in production.

Making production lines more flexible: The current simulation depicts production as a rigid system in which each product is always passed to the right until the production process is complete. In reality, however, the machines are often distributed in a hall and different machines have to be reached by means of transportation. The simulation could be extended to simulate this realistic distribution of machines and the necessary logistical planning by implementing means of transportation between the machines.

Consideration of machine availability: The simulation currently assumes 100% availability of the machines without taking the probability of failure into account. In an extension, different scenarios with different failure probabilities and disturbance variables could be simulated. This would increase the complexity of production planning and highlight the need for efficient bottleneck management. A realistic simulation of machine availability and breakdowns would bring the logistical challenges and flexibility of production planning even more into focus.

6 Outlook: VR-LEAN-Learning-Factory international

visTOC has become an integral part of LEAN teaching at Karlsruhe University of Applied Sciences. Students can use their laptops to experimentally train the effects of batch sizes and set-up times as a function of the number of machines and cycle times for various production programs in the 2D application and in 3D training sessions. As a further step, it is now planned to expand this VR LEAN Learning Factory by having other users integrate their LEAN games into the hall and thus make them available to everyone internationally.

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Development of a business game to build and deepen students' understanding of lean management

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Abstract

Lean management methods and procedures are taught in the classroom, but student success measurements and real-world applications show that students lack a deeper understanding of the lean mindset and methods. In the context of improving the quality of teaching, the challenge was therefore to build up this understanding. This article describes how the design of a plan game to improve the understanding of lean methods was approached and implemented in a plan game that can be used in practice. Furthermore, the lessons learned during the development process are presented.

Lean in Healthcare and Services

The Effectiveness of Lean Improvement Methodology in Healthcare

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Abstract

3/29/2024

The growing need for improvement within the healthcare sector has precipitated an accelerated adoption of change management and performance excellence models across the industry. While the uptake of Lean, Six Sigma, and other Continuous Improvement models initially gained traction primarily in operational domains, such as enhancing patient throughput and optimizing the allocation of limited resources (e.g., laboratory, imaging), there is a compelling argument that these models hold equal promise for addressing other critical dimensions of healthcare delivery, as delineated by the Institute of Medicine: Safety, Effectiveness, Patient-centeredness, Timeliness, Efficiency, and Equity.

Although the core concepts of Lean methodology remain universally applicable across various industries and contexts, the successful and sustained implementation of Lean principles in healthcare necessitates a meticulously crafted and tailored approach, informed by a nuanced understanding of the multifaceted factors that characterize the sector. While these factors span a broad spectrum, they can be categorized through a modified version of the Clark and Estes gap analytical framework. Under this framework, three primary components emerge: Knowledge, Motivation, and Organizational barriers. This presentation highlights the most noticeable aspects within each of these aforementioned categories and furnishes a concise synthesis of research findings pertaining to the adoption of best practices across these domains within the healthcare industry.

Focusing specifically on Lean implementation within Academic Medical Centers in the United States, this presentation underscores the significance of aligning Lean methodologies with other improvement models in healthcare, alongside highlighting the pivotal role of a Lean coaching culture in engendering the success of improvement endeavors. While the Lean improvement model predominates as the most prevalent methodology adopted by hospitals in the United States (as evidenced by its adoption in 48.9% of hospitals according to recent surveys), numerous institutions are complementing their Lean frameworks with other Continuous Improvement methodologies such as Six Sigma, Baldrige, or the Institute of Health Model for Improvement. This presentation expounds upon the overarching alignment of these models and delineates strategies through which healthcare organizations can leverage these supplementary frameworks to advance their capacity-building training programs.

Operational waste and efficiency: Lean Manufacturing insights from a Brazilian medication distribution center

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Keywords: lean manufacturing, pharmaceutical supply chain, waste reduction, interpretive structural modeling

1 Introduction

The constant pursuit of eliminating waste and meeting the demands of a dynamic market has led the Pharmaceutical Supply Chain (PSC) to adopt Lean manufacturing principles, which originated in the Toyota Production System (TPS). The TPS aims to eliminate waste, defined as activities that consume resources without adding value, categorized into overprocessing, overproduction, excess inventory, transportation, unnecessary motion, defects, and waiting (Ohno, 1988). The PSC's complexity and need for high-quality service make it particularly susceptible to these wastes, which can significantly impact operational efficiency and product effectiveness (Papalexi et al., 2019).

To address these issues, this study aims to analyze the waste identified in a medication distribution center in Teresina using Lean tools and Interpretive Structural Modeling (ISM). ISM helps understand the interrelationships between different wastes, breaking down complex issues into manageable parts (Ali et al., 2020). This approach involves developing a structural matrix based on expert opinions to identify and prioritize the key wastes affecting the distribution center's operations.

The study seeks to investigate the relationships and dependencies between these wastes, considering the unique challenges of the PSC, such as regulatory pressures and the involvement of multiple stakeholders. The primary research question focuses on understanding how these wastes interrelate and influence each other within the context of pharmaceutical distribution.

2 Methodology

This research adopted a mixed-methods approach, integrating both qualitative and quantitative data to achieve a comprehensive understanding of the operational wastes in the medication distribution center. The study began with an extensive literature review on Lean philosophy, logistics, distribution center operations, and process mapping. This theoretical framework informed the design and implementation of the research, ensuring that the methodologies applied were grounded in established academic and practical principles. Essential Lean tools such as Value Stream Mapping (VSM) and the 5S methodology were identified as suitable for waste identification and analysis within the pharmaceutical supply chain.

The primary data collection involved on-site observations and semi-structured interviews with employees at the distribution center. The observations focused on daily operations, capturing the flow of materials and information, and identifying inefficiencies and waste. Semi-structured interviews were conducted with eight key personnel, including the distribution center manager, loss manager, loss supervisor, reverse logistics supervisor, loss coordinators, process analyst, and loss assistant. These interviews provided insights into the specific challenges and waste-related issues encountered in their respective roles. The combination of observation and interviews ensured a holistic view of the operational processes and waste dynamics.

ISM was employed to analyze the collected data. ISM is a qualitative modeling technique that helps in understanding complex relationships and dependencies among various elements. In this study, ISM was used to develop a hierarchical model illustrating the interrelationships between the identified wastes. The process involved creating a Structural Self-Interaction Matrix (SSIM), converting it into an initial and then a final accessibility matrix, and finally constructing the ISM model. This model revealed the driving power and dependency of each type of waste, providing a clear framework for prioritizing waste reduction efforts. The ISM methodology was crucial in simplifying the complexity of waste interdependencies and offering actionable insights for improving the distribution center's operations.

3 Main Findings

The study identified ten primary wastes within the medication distribution center: overproduction, excess inventory, transportation, waiting, excess motion, defects, and manual activities. Specifically, overproduction was observed in purchasing large quantities of products with low inventory turnover, leading to high volumes of expired inventory. Excessive transportation waste was identified due to the distant docks from storage locations, causing significant delays and inefficiencies. Other critical wastes included congestion of conveyor baskets and high manual activity levels, contributing to substantial waiting times and operational bottlenecks. Additionally, defects were noted in final order verifications, and the lack of shipment tracking further complicated the distribution process.

The application of ISM provided a detailed understanding of the relationships and dependencies among these wastes. The ISM model revealed that particular wastes, such as distant docks and manual activities, have high driving power, significantly influencing other wastes. For instance, inefficient dock locations led to increased transportation times, which in turn caused delays and waiting times across the entire distribution chain. Conversely, issues like expired inventory and damaged goods were identified as dependent wastes, heavily influenced by upstream inefficiencies such as overproduction and poor inventory management. The hierarchical structure of the ISM model underscored the need to prioritize addressing high-impact wastes to achieve broader operational improvements.

4 Discussion

The findings highlight the critical need for strategic interventions targeting high-impact wastes to enhance the overall efficiency of the medication distribution center. Addressing transportation and manual activity-related wastes emerged as a top priority. Optimizing dock locations and implementing automation could significantly reduce waiting times and minimize errors, thereby enhancing inventory management and operational flow. Furthermore, the study suggests that improving inventory management practices to prevent overproduction and excess inventory would mitigate the risks of expired and damaged products, leading to cost savings and improved service quality.

The ISM model's insights into waste interdependencies are particularly valuable for developing targeted waste reduction strategies. By focusing on primary wastes with high driving power, the distribution center can implement changes that cascade positive effects on other dependent wastes. For example, reducing manual activities through automation speeds up operations and reduces the likelihood of errors and defects in order processing. Additionally, the study emphasizes the importance of continuous improvement practices and regular audits to sustain efficiency gains and adapt to evolving operational challenges.

5 Conclusion

This study successfully identified the key wastes in the medication distribution process and established their interdependencies using Interpretive Structural Modeling (ISM). The ten primary wastes identified include overproduction, excess inventory, transportation, waiting, excess motion, defects, and manual activities. Addressing these wastes, particularly those with high driving power such as distant docks and manual activities, can significantly improve efficiency and cost-effectiveness. Optimizing dock locations and implementing automation are recommended strategies to reduce waiting times and minimize errors, enhancing overall operational efficiency. Future research should explore the application of fuzzy MICMAC analysis further to quantify the relationships and intensities of these wastes, providing a more nuanced understanding of their impacts.

This research contributes to the literature on Lean management in the pharmaceutical industry by demonstrating the applicability of Lean tools and ISM in identifying and analyzing operational wastes. The study highlights the complex interdependencies between different types of waste and provides a structured approach for prioritizing waste reduction efforts. By integrating Lean tools with ISM, the study offers a robust waste identification and management framework, enhancing the theoretical understanding of waste dynamics in the pharmaceutical supply chain.

The study offers a clear roadmap for waste reduction in medication distribution centers for practitioners. Implementing the suggested improvements can enhance operational efficiency, reduce costs, and improve service quality. The findings underscore the importance of regular waste audits and continuous improvement practices. This case study, however, is limited to a single distribution center, and the findings may not be generalizable to other settings without further validation. Future research should include a broader range of distribution centers and consider additional variables such as regulatory changes and market dynamics. Applying advanced techniques like fuzzy MICMAC can provide deeper insights into the strength and intensity of waste relationships, facilitating more effective waste reduction strategies.

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Macro and Micro Value Stream Mapping in a wheel management service company

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Abstract

The current challenges faced by manufacturing companies and the service industry are influenced by several significant global trends. Globalization presents both challenges and opportunities. On the one hand, globalization fosters market expansion and diversification. On the other hand, it intensifies cost pressures for manufacturing and service companies. (Bertagnolli, 2022)

In the ever-evolving landscape of contemporary business, the pursuit of operational efficiency has emerged as a paramount objective for companies of all sizes and sectors. However, for small and medium-sized enterprises (SMEs), the path to achieving operational excellence often comes fraught with challenges. Historically, businesses have encountered difficulties in optimising their warehouses due to a multitude of external factors, including partner relationships, logistics, technology, and the state of the global economy. The modernisation of business operations and the rapid shift to a digital economy have brought about new challenges (Kattepur, 2019). Warehouse management practices have evolved significantly, driven by the expansion of e-commerce and the adoption of multichannel and omnichannel distribution systems. This evolution has led to the transformation of supply chain networks, the introduction of autonomous mobile robots, the rise of micro-fulfilment centres, and the increased demand for same-day and next-day delivery services, but consists of typically 7 main functions and process steps (ten Hompel & Schmidt, 2008).

Whereas Lean management is a prominent and well proven approach to optimizing processes throughout the value chain. It is primarily centered on the identification and conversion of inefficiencies into value-adding activities from upstream to the downstream side (Helmold, 2020). A methodology for assessing and visualization of process waste and inefficiency is value stream mapping, creating an process model between customer and supplier (Rother & Shook, 2003). Another tool from industrial engineering based on the task level of a process is the process activity mapping or process analysis in general (Hines & Rich, 1997). Also Taylorism based approaches focussing on time and ergonomics like REFA time study are relevant in assessing workplace environments (REFA-Institut, 2021).

These are representations of a company's activities at different levels of detail, providing information at different aggregation levels and – traditionally – addressing different target groups. These groups are typically stakeholders in a planning project like project, process and production engineers, but also logistics specialists, ergonomists, business managers and others more (Schenk et al., 2010). In this paper, we argue that a synthesis of both approaches combined in a so called macro- and micro- value stream map (VSM) will support

the effects of lean projects in SMEs with seasonally fluctuating value creation processes (Figure 1).

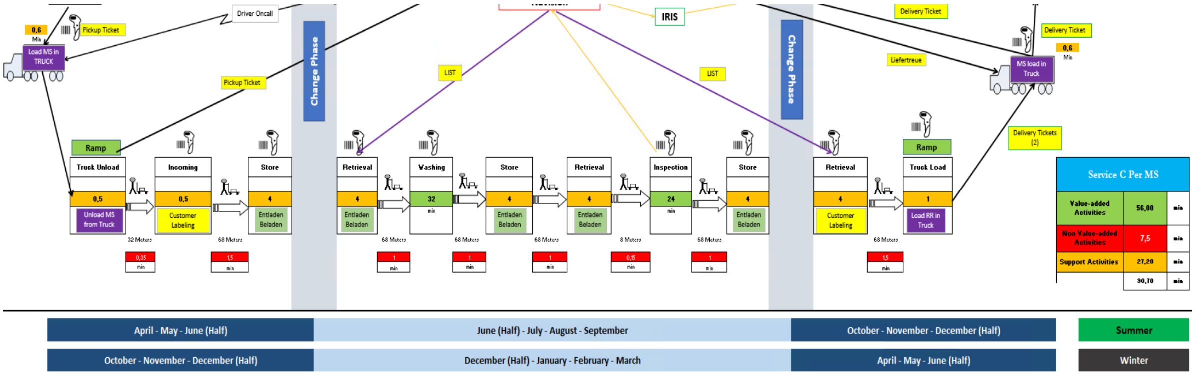

Figure 1: Example of Macro VSM

The incorporation of the classification of value added, non-value added and support activities on a higher level will support the necessary focus on specific improvement potentials at certain process steps resp. activities.

This paper tries to give insight into both levels, using a case study research oriented approach (Yin, 2018), represented by a wheel storage facility. In this article, we examine the following research questions:

- *RQ1: What are the different and waste related activities in a wheel storage facility?*
- *RQ2: Can process optimization be done with a combination of a Macro- and Micro View and which effects can be expected?*

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Lean 4.0

Lean 4.0 and the Portuguese manufacturing

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Keywords: lean 4.0, industry 4.0, lean, I4.0, lean management

Abstract

The technological development transformed the world and the fourth and current industrial revolution bring greater challenges to the companies and focus on the capture and sharing of information and in the human-machine interaction. The lean methodology is becoming more used by companies aiming to give answer to the market changes, to the pressure on costs, to the pressure for waste disposal, to the increasingly shorter deadlines and to the changes on the population consumption behavior. The pressure for constant innovation and adaptability towards such changes increases the complexity to the companies in ensuring their performance and survival. As lean, the role of new technologies is to bring greater efficiency and effectiveness to the production process, supporting and allowing greater adaptability capacity and control over the flow. The recent I4.0 technologies in development and the lean philosophy are in the centre of the current debates regarding the contribution of each one to the companies' performance, what´s the correct order to implement them and in which intensity to obtain the best relation of such integration. Applying the survey methodology, a survey was held to understand the Portuguese industrial panorama, being analyzed 108 answers. The current study analyzed and confirmed the correlation between Lean and I4.0, had verified the way companies integrate Lean and I4.0, and the impact over their performance. Besides mapping the overview of the Portuguese industrial fabric over the subject in matter.

Synergizing Kanban and ERP: A Digital Card-Based Control System for Enhanced Lean Management

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Keywords: lean management, kanban, digitalization, production coordination

1 Introduction

Efficient coordination of goods flow within production processes remains a critical challenge in operations management. Various methodologies have been developed to optimize this coordination, with Kanban, a card-based control system rooted in the Toyota Production System, being a cornerstone in Lean Production environments. Kanban systems, characterized by their decentralized control mechanisms, effectively regulate work-in-process (WIP) by linking production stages through a pull system that signals demand for upstream activities based on downstream needs (Thürer, Fernandes, Stevenson, Qu, & Li, 2019). This decentralized approach allows for local optimization, particularly in environments with predictable and repetitive production flows.

Simultaneously, the rise of digitalization has seen Enterprise Resource Planning (ERP) systems become integral for order control and resource management across manufacturing sectors. ERP systems centralize data management, providing comprehensive oversight of production processes and facilitating real-time decision-making.

2 Problem Statement

Despite the widespread adoption of ERP systems, many manufacturing companies struggle with real-time data feedback from production processes to ERP systems, leading to suboptimal utilization of ERP capabilities. This results in inaccurate cost calculations, delivery time estimates, and order status tracking. The lack of timely and accurate data hampers operational efficiency and undermines the potential of ERP systems in driving effective decision-making and process optimization.

The central challenge lies in integrating decentralized control systems like Kanban with centralized ERP systems to create a cohesive and responsive production environment. Kanban's simplicity and visual management strengths are offset by its limited capacity to balance workloads dynamically across different stages of production, particularly in settings with high variability. In contrast, ERP systems, while powerful in aggregating and analyzing data, often suffer from delayed and inaccurate inputs from the production floor, leading to inefficient resource allocation and extended lead times. Addressing these limitations requires a novel approach that synthesizes the strengths of both systems to enhance production coordination, streamline operations, and improve overall efficiency in Lean Management contexts.

3 Objective

This paper introduces a novel approach that synthesizes the simplicity and visual clarity of Kanban with the computational and data integration strengths of ERP systems. The goal is to develop a digital card-based control system that leverages the strengths of both methodologies to enhance production coordination, streamline operations, and improve overall efficiency through a transparent overview of the current orders in production in Lean Management contexts. The Kanban board should visualize work in progress (WIP) and provide a clear signal of any bottlenecks in production. Individual orders have potentially different complexities, which should be represented on the Kanban board.

4 Methodology

The research employs an intervention-based methodology, focusing on a case study of a Saxony-based manufacturer specializing in tools for punching and injection moulding processes. The company faces challenges in production planning and organization due to the limitations of its existing ERP system. These challenges include inadequate coverage for production planning and delayed feedback loops from the shop floor to the ERP system. Additionally, obtaining a clear, concise overview of the current production orders is too cumbersome.

The intervention involved introducing a digital Kanban system coupled with Node-Red, a flow-based development tool, to create a tailored shop floor data collection system. This system allows employees to easily capture and relay relevant data to the ERP system, thereby enabling more accurate and timely production data integration. The collected data also supports the training of an AI model designed to improve future job time predictions, further enhancing planning accuracy and responsiveness to deviations. During regular workshops, the system was further refined to address the needs of the users.

5 Results

The implementation of the digital Kanban system provided a clear, visual representation of all orders and deadlines, thereby facilitating efficient and transparent workflow control. If an individual process exceeds its WIP limit, the corresponding column is highlighted in red to signal a bottleneck, as shown in Figure 1. Additionally, the orders are automatically sorted according to their due date. Dates of overdue orders are marked red, and an email is sent to project management. Furthermore, each order can be given a complexity score to differentiate between larger, more complex, and simpler orders. The sum of all the complexity scores in a column is also displayed. These features provide project management with the transparency and necessary information about the order status in production.

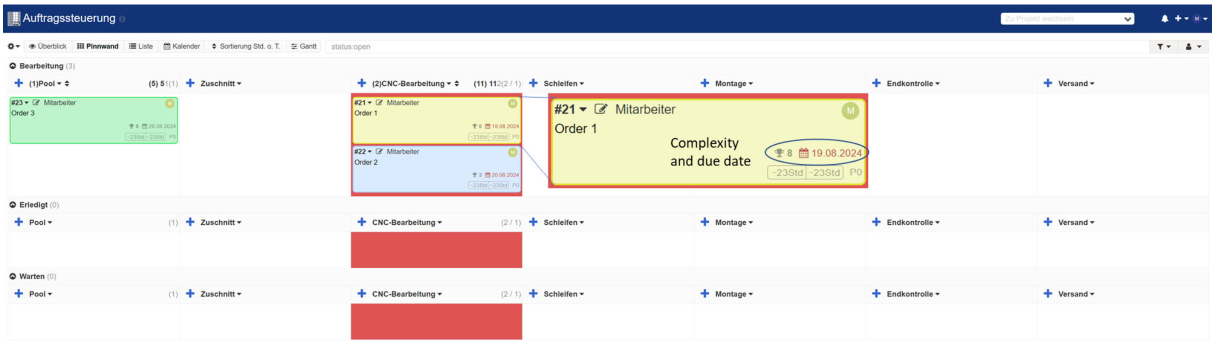

Figure 1: Screenshot of a representation of the introduced Kanban board (This is only an imitation of the real board so as not to disclose confidential company information.)

Node-Red's user-friendly interface enabled seamless data capture and feedback directly at the workstation, minimizing the burden on employees and ensuring continuous data flow to the ERP system. This data collection process, integrated into regular operations, also allowed for the ongoing development of an AI model capable of refining time predictions for future orders.

The system's transparency and ease of use contributed to enhanced employee engagement and data accuracy, leading to better resource allocation, reduced lead times, and increased overall productivity. Additionally, the data-driven AI model showed promise in predicting intermediate and final deadlines, further supporting proactive management of production schedules.

6 Conclusion

This research highlights the synergistic potential of combining Kanban and ERP systems within a digital framework to address common challenges in Lean Management. The digital card-based control system not only enhances the visibility and control of production processes but also leverages digital data integration to optimize resource allocation and improve decision-making. By implementing this integrated approach, manufacturing companies can achieve greater operational efficiency, reduced waste, and a stronger competitive edge in the market.

The study's findings underscore the importance of customizing digital solutions to meet specific organizational needs, with the potential for broader application across various manufacturing sectors. Future research will focus on refining the AI model and exploring the scalability of the system in different production environments.

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Reinforcement learning in layout planning - development of mathematical models for the automated evaluation of factory layouts

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Keywords: facility layout problem, factory planning, automated facility layout planning, facility layout evaluation

Abstract

This study presents a framework for the computer-aided and automated evaluation of the quality of factory layouts with regard to various criteria. This evaluation forms the basis for future layout optimisations based on various algorithms. The current state of the art uses a grid method to divide factory layouts into elementary cells. This system is not compatible with typical industry planning tools without pre-processing. The presented framework enables the evaluation of factory layouts that are defined as vector data in a continuous space and thus the direct import of industry-typical file formats. In addition to the material flow, a variety of other aspects from the categories of logistics, adaptability and environmental influences are evaluated to enable a holistic view of the factory layout. A weighted summary of partial evaluation aspects can then be used to generate use case-related target functions for optimisation algorithms or reinforcement learning. An exemplary visualization of two versions of layouts utilising a given set of production units and a fixed floorplan is shown in Figure 1.

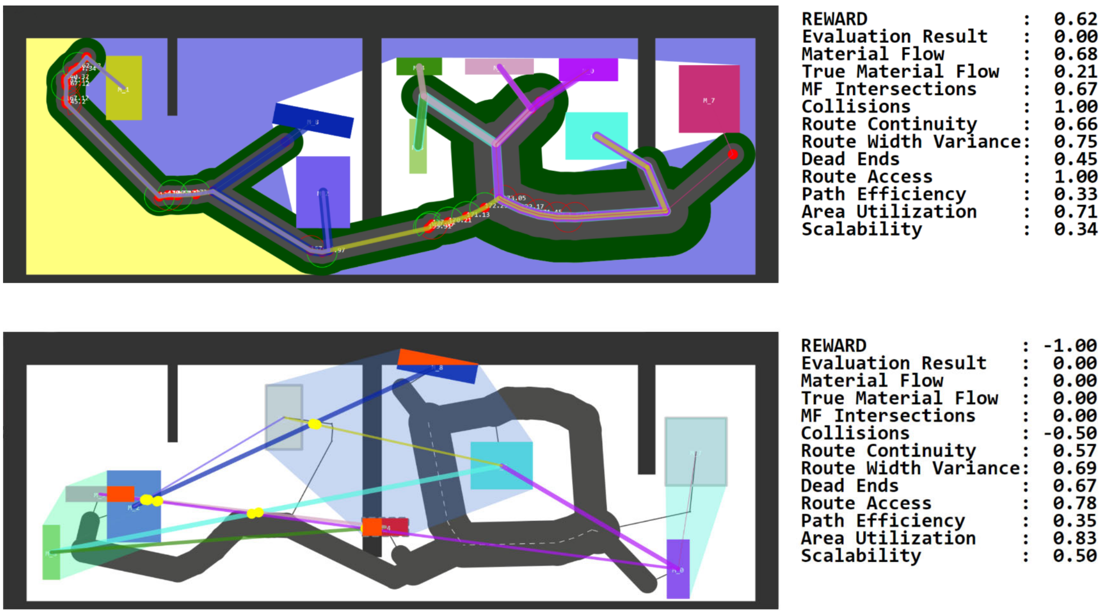

Figure 1: Visualisation of different layout evaluation criteria

The upper part of the figure illustrates production units and pathways. The green outline indicates the true width of the pathways, which can be used to select forklifts or AGVs. The angles drawn at bends in the pathways help evaluate the straightness and continuity of the paths. Material flow is routed along these pathways, with color indicating the sink production unit and line width representing material flow intensity. The free space in the layout is divided into white, yellow, and blue sections: white represents machine groups by proximity, yellow denotes the largest connected free space, and blue shows the remaining free space.

The lower part of the figure presents additional viable analysis results. Here, the material flow is depicted in a classical manner, connecting the center points of the production units. Collisions between machines and walls are highlighted in orange. Due to the alternative placement of the production units, the analysis algorithm has identified three different machine groups.

The right side of the figure displays the analysis results for selected criteria, normalized to a range of 0.0 to 1.0. The full article will detail the calculation formulas and required parameters for all evaluation criteria, thus enabling the use of the evaluation system for downstream evaluation in machine learning algorithms.

Lean Application

Continuous improvement in Finnish food industry companies

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Abstract

The Finnish food industry is dominated by small businesses. About 86 percent are micro-enterprises. The food industry is a low-margin business, so it is crucial to develop the business by eliminating non-value-added activities.

This presentation presents the results of a survey of 201 companies in the Finnish food industry. The responding companies are of different sizes and operate in different food sectors. The companies were asked to rate how well the following statements describe their company over the past three years:

- *We have developed our production processes.*
- *We are committed to continuous improvement.*
- *We have improved the rationality of our operations by eliminating the unnecessary.*
- *We have standardised our working methods.*
- *We have focused on improving efficiency.*

From these statements, a summary variable was created to describe the use of lean thinking principles by companies. The presentation describes which types of companies in the food industry use lean thinking principles. It also describes how these companies rate their performance in different areas.

Operational excellence beyond the factory floor: a case study in Lean Office

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Keywords: lean office, administrative efficiency, automotive industry, value stream mapping, information flow management

1 Introduction

The introduction of Lean Office practices into administrative activities marks a significant advance in the quest for organizational efficiency by adapting principles from Lean Manufacturing to optimize critical information flows in modern administration. This approach reduces waste, enhances process quality, conserves resources, and improves customer satisfaction by eliminating redundant tasks and accelerating access to relevant data (Womack & Jones, 1996; Womack et al., 1990). Refining these flows enables quicker and more accurate strategic decisions, essential in a constantly evolving business environment, thereby boosting the organization's competitiveness (Ohno, 1988).

This study explores the implementation of Lean Office in a multinational automotive company, focusing on how operational excellence can be extended from the production floor to administrative functions. The Lean methodology, renowned for its waste elimination capabilities in manufacturing, is adapted to the administrative context to streamline information flows and improve inter-departmental communication. The research explicitly targets the payment operations at one of the company's dealerships, analyzing and identifying discrepancies in the information system.

In this regard, the primary objective of this study is implementing Lean Office techniques to map and propose enhancements to the information flow associated with the payment process, aiming to achieve more efficient operations with reduced errors and rework. This initiative seeks to identify and diminish common administrative wastes such as waiting times, uncontrolled stock management, and unnecessary processing. The study's importance is highlighted by the automotive industry's need for adaptability and ongoing improvement in a highly competitive and dynamic market. Administrative efficiency is vital for supporting lean manufacturing operations and fostering innovation and customer satisfaction, which are crucial for sustaining the company's competitive edge globally.

2 Methodology

The methodology implemented in the Lean Office study at a dealership of a multinational automotive company was meticulously crafted to deliver a thorough and actionable analysis of administrative operations, with a specific focus on the payment process. The methodological framework comprised several critical stages: it began with defining the unit of analysis, focusing on a particular dealership of the multinational. This selection was based on the pivotal role of its payment process in studying information flows and identifying inefficiencies. The clear delineation of the analysis unit allowed for an intense focus on the unique aspects of the dealership's administrative processes, enabling a more detailed and contextual examination of current practices.

At the core of the methodology was the use of Value Stream Mapping (VSM), which commenced with creating a current state map to understand existing processes and pinpoint inefficiencies. This map was essential in visualizing all activities involved in the payment process, from demand receipt to final execution of services, highlighting areas of delays, redundancies, or other forms of waste. Following this initial analysis, a future state map was developed, incorporating proposed improvements based on Lean principles, such as the elimination of non-value-added activities, reduction in cycle times, and overall process efficiency enhancement.

To augment the VSM, the research also incorporated interviews and data collection directly from the workplace, along with the review of internal documents and information systems. These additional data collection efforts ensured a deep understanding of workflow dynamics and inter-departmental interactions, crucial for the effective implementation of Lean Office practices. The analysis of the collected data followed a systematic procedure to ensure that the proposed interventions were practical, achievable, and aligned with the company's strategic goals. The process was meticulously documented to ensure that the implemented changes could be evaluated for effectiveness and sustainability, providing a replicable model for other parts of the organization or companies facing similar challenges.

3 Main Findings

The main findings of this research include several significant insights into the inefficiencies and potential improvements in the information flow within a multinational automotive company's administrative processes. Firstly, the study identified critical inefficiencies in communication between various departments. These inefficiencies often led to delays, miscommunication, and a lack of coordination, resulting in increased lead times and decreased overall process efficiency. The application of Lean principles aimed to streamline communication, ensuring that information flowed seamlessly between departments without unnecessary delays or misunderstandings.

Moreover, the research found uncontrolled inventory management to be a significant source of waste. Excessive inventory ties up capital and increases the risk of obsolescence and storage costs. By applying Lean techniques, such as Just-In-Time (JIT) inventory management, the company could reduce unnecessary stock levels, thereby freeing up resources and reducing costs. This approach also contributed to a more responsive and flexible supply chain better aligned with actual demand.

Another significant finding was the excessive processing and rework that occurred due to non-standardized procedures and a lack of process automation. Manual data entry and repetitive tasks were prevalent, leading to errors and rework. Implementing automated systems and the standardization of processes significantly reduced these issues. Reducing the number of systems from nine to three streamlined operations, reduced the complexity of workflows, and minimized the potential for errors.

The research also highlighted the impact of these improvements on the cycle time (Lead Time). There was a substantial reduction in the time required to process and resolve issues, dropping from an average of 14 days to significantly fewer days. This improvement not only enhanced operational efficiency but also improved the company's ability to meet customer expectations promptly, thus boosting customer satisfaction.

Finally, the research demonstrated the importance of continuous monitoring and iterative improvements. By regularly assessing the state of the processes and implementing incremental changes, the company could maintain high efficiency and continuously adapt to evolving business needs. This proactive approach ensured that improvements were sustained over time and that new inefficiencies were promptly addressed.

4 Discussion

The results' analysis revealed that implementing Lean Office in administrative activities can substantially benefit operations management. The improvements made not only reduced waste but also significantly enhanced the company's responsiveness to market demands, thereby increasing customer satisfaction. This finding underscores the value of Lean principles in administrative contexts, where inefficiencies can often be overlooked compared to manufacturing environments.

Additionally, the analysis identified that automating processes was crucial in achieving these benefits. Automation reduced the manual handling of tasks, minimizing errors and allowing employees to focus on value-adding activities. This shift improved process efficiency and enhanced job satisfaction among employees, as they could engage in more meaningful and less repetitive work. The analysis further identified that standardizing processes was critical in reducing variability and ensuring consistent outcomes. By establishing clear procedures and guidelines, the company could ensure that all employees followed the best practices, leading to more predictable and reliable results. This standardization was essential in an administrative setting, where procedure variations could lead to significant inefficiencies and errors.

5 Conclusion

In conclusion, applying Lean Office principles in a multinational automotive company proved to be highly effective in enhancing the efficiency and effectiveness of administrative processes. This research demonstrated that using tools such as VSM and implementing Lean practices can result in substantial gains in operational efficiency, reduced waste, and improved process quality. The findings underscored the significant impact of streamlining communication, standardizing procedures, and automating processes to reduce cycle times and minimize errors.

Theoretically, this study contributes to the broader understanding of Lean methodologies beyond the manufacturing environment. It validates the applicability and benefits of Lean Office principles in administrative settings, thereby expanding the scope of Lean theory. The research provides a framework for other scholars to explore Lean applications in diverse administrative and service-oriented environments. It also reinforces the importance of continuous improvement and the systematic elimination of waste as fundamental principles that can be adapted to various organizational contexts. Practically, this research offers valuable insights for managers and practitioners aiming to enhance administrative efficiency within their organizations. Implementing Lean Office principles significantly improved communication, inventory management, and process standardization. These improvements resulted in cost savings, reduced lead times, and enhanced overall organizational responsiveness and customer satisfaction. The study provides a practical roadmap for organizations looking to adopt Lean Office practices, including specific techniques such as 5S, Kaizen, and JIT inventory management.

Future research should continue to explore the application of Lean Office principles in different administrative and service sectors. Investigating the integration of advanced technologies, such as artificial intelligence and machine learning, could offer further opportunities to optimize information flows and enhance decision-making processes. Additionally, longitudinal studies could examine the long-term effects of Lean Office implementations on organizational performance and employee satisfaction. By staying at the forefront of technological developments and continuously refining Lean practices, companies can maintain a competitive edge and drive sustainable operational excellence.

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A trade-off between lean and resilience in Supply Chains

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Keywords: lean, resilient, value creation, lean & resilience-co-integration

Abstract

The COVID-19 pandemic showed that the strongest and most successful organizations were those that archieved an optimal balance between lean and resilience in their Supply Chains. During the crisis many companies have had to learn how to operate in a highly unstable and unpredictable environment (Choi, 2020; Ivanov, 2020a; Ivanov and Das, 2020; Paul and Chowdhury, 2020a; Singh et al., 2020). The question then arises: how can these learned lessons and created resilience assets (i.e. physical and information components for supporting operations under highly uncertain and vulnerable conditions) be meaningfully used in post-COVID-19 supply chain management? (Queiroz et al., 2020; Jang et al., 2021).

The term resilience is derived from the natural sciences. It describes the ability of a system to return to its original form after a disruption (Annarelli & Nonino, 2016, p. 2 f.). The natural science perspective was supplemented by key elements of ecological, social, psychological, economic, organizational and emergency resilience. Based on this, supply chain resilience is understood as the ability of a supply chain to prepare for, respond to and recover from disruptions and unexpected events while maintaining operations within the logistics network (Ponomarov & Holcomb, 2009, p. 131).

Lean is a management paradigm developed at Toyota Motor Corporation, and it is widely known as the Toyota Production Systems (TPS). TPS has continuously evolved and became known in the West, initially as just- in-time (JIT) production, and was subsequently popularised as lean production or lean thinking (Machado, V.C., Duarte, S. (2010). The real picture is that lean strategy reduces costs and waste from supply chain, but also reduces supply chain resilience. Thus, creating and assessing the balance between cost savings principles (lean) and resilience is rather than a necessary. This balance between efficiency and resilience could be reached through design-for-resilience approach. Hence, the necessity for balance between resilience and lean arises as a new form of trade-off in supply chain management.

The traditional understanding of supply chain management has been design-for-efficiency and responsiveness. Efficient and responsive supply chains and operations are determined by the principles of leanness and agility. The key idea behind such agile operations and supply chain designs is to utilise the available resources (i.e. materials, time, capital, technology and workforce) at the highest possible degree to avoid waste and maximise profitability.

Design-for-Resilience, meanwhile, assumes that resilient supply chains and operations are designed to absorb unexpected, severe disruptions (e.g. natural disasters, fires at facilities, strikes or epidemic outbreaks) and to restore operations when faced with disruption. Resilience helps to mitigate the impact of disruptions using some form of redundancy (e.g.

inventory, capacity buffers or back-up suppliers) and to recover to an original or even better performance (Ivanov, 2020).

The paper is structured as follows. First, basic definitions related to supply chain resilience will be summarised. Next, the concepts of lean strategy and lean supply chain are introduced. Thereafter, a framework for creating efficient trade- off between lean and resilience will be offered. This trade-off can help to create more efficient and less vulnerable supply chains. The paper describes importance of developing a new approach in the Supply Chain Management, based on considering the resilience as an inherent, active and value-creating component of operations management decisions, rather than as a passive "shield" to protect against rare, severe events. Finally, the paper ends with a brief conclusion.

Enhancement of in-store product replenishment flow and introduction of pull approach in a food retail chain

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Keywords: lean principles, pull replenishment, food retail efficiency, ergonomic improvements

Abstract

*This study aims to apply Lean concepts and principles to the logistical process of product replenishment on store shelves in one of the largest food retail chains in Portugal. Currently, replenishment follows a "push" approach based on the arrival of products at the store's warehouse, resulting in inefficiencies in the use of labour especially due to excessive handling and motion. A transition to a "pull" approach, based on real-time consumption, is proposed to increase efficiency, eliminating pallets and the ergonomically unfavorable product separation process. During a 5-day test, Lean principles and the use of ergonomic trolleys reduced adverse movements. The new system improved efficiency, reducing labour requirements from 28.4 to 19.2 man*hours per day, reducing unnecessary handling and increasing product availability.*

1 Background

The food retail sector faces constant challenges due to intense competition and growing consumer expectations for quality and low prices (Busso & Galiani, 2019; Hamilton et al., 2020). In this context, operational efficiency and innovation are essential for the sustainability and success of companies. The Lean philosophy, with its principles of continually eliminating waste and maximizing customer value (Krafcik, 1988; Womack et al., 1990), has proven to be an effective approach in several industrial sectors. Recently, this philosophy has also been applied to the retail sector, where optimizing logistics processes can result in significant performance improvements.

The Lean philosophy, developed from the Toyota Production System, is widely recognized for its effectiveness in improving industrial processes. According to Womack & Jones (1996) Lean principles include specifying value from the customer's point of view, identifying the value stream, creating a continuous flow, implementing a pull system, and continuously seeking for perfection. In the manufacturing context, these principles have resulted in significant cost reductions, improvements in quality and increased efficiency (Krafcik, 1988; Liker, 2004). In the retail sector, the application of Lean principles are still in the development phase, but the Initial studies show promising results. For example, (Lukić, 2012) highlight that implementing Lean in retail operations can lead to better inventory management, reduced waste and increased customer satisfaction. However, transitioning from a “push” to a “pull” replenishment approach in retail presents unique challenges due to the dynamic and unpredictable nature of consumer demand.

The "push" replenishment approach traditionally used in retail is characterized by the distribution of products based on forecasts and fixed schedules, regardless of the actual replenishment needs on the shelves. While this system may seem efficient, it often results in excess inventory, unnecessary product handling, and high rates of obsolete products. Furthermore, the lack of flexibility of the "push" approach prevents rapid response to changes in consumer demand, leading to frequent stockouts (Scott et al., 2011)

In contrast, the "pull" replenishment approach is based on replenishing products based on actual demand, that is, products are replenished as they are consumed by customers. This system has the potential to reduce waste, improve efficiency and increase product availability on shelves. According to Hopp & Spearman (2004) the "pull" system can create a continuous flow of products, minimizing waiting time and excess inventory. However, its implementation requires significant cultural change and investments in training and technology.

Case studies on the application of Lean in retail show that the transition to a "pull" system can result in substantial improvements. For example, (Halder & Pati, 2011) documented a study in a supermarket chain in India where implementation of the “pull” system led to a 20% reduction in inventory levels and a 15% increase in product availability. Similarly, the study by Zokaei & Simons (2006) in a retail chain in the United Kingdom demonstrated that the application of Lean principles significantly reduced cycle times and improved customer satisfaction.

However, the literature also highlights the challenges associated with implementing the “pull” system in retail. The need for accurate and real-time data, the ability to respond quickly to changes in demand and coordination between different departments and suppliers are some of the barriers identified (Storey et al., 2005). Furthermore, resistance to cultural and organizational change can make it difficult to adopt the “pull” system.

The most important principles being applied in this study is the Flow and Pull Flow, presented in most operational excellence models such as Lean, Shingo Model (Miller et al., 2013), or Toyota Way (Liker, 2004). The proposal in this study is a transition from a "push replenishment" approach, which lacks flow, to a "pull replenishment" method with significant improvements in efficiency, aimed at reducing waste in the process. In addition to addressing efficiency aspects, this new replenishment system should also incorporate substantial ergonomic improvements for operators. The objective is for this new system to result in significant enhancements in productivity, reduction of product shortages on shelves, and overall working conditions.

2 Methodology

The study was conducted in one of the largest food retail chains in Portugal, using an action research approach. The main intervention was the transition of the product replenishment system from "push" to "pull".

Firstly, a preliminary analysis of the existing “push” replacement system was carried out. Nine food aisles were selected to be monitored. For a week, processes, operating times and inefficiencies were documented. Then, a detailed plan was then developed for the implementation of the "pull" system, which included the restructuring of replenishment processes and the introduction of ergonomic trolleys.

During a 5-day test period, manual aisle checks were carried out to identify actual replenishment needs before pallets were sorted. New ergonomic trolleys have replaced traditional pallet trucks, reducing unfavourable movements and eliminating the existing depalletization process. This depalletization process consisted of passing the products that came mixed on pallets from the supplier to other pallets by organized by product type. Data was collected through direct observation of replacement processes, measurement of daily man*hours, and interviews and questionnaires with operators to assess ergonomic conditions and satisfaction.

Data analysis was based on the use of performance metrics that included the number of labour hours, the quantity of products handled, transport movements and the level of operator satisfaction to compare the efficiency of the "push" and "pull" systems.

3 Results

The results of this study are demonstrated in this section, which contains the characterization of the initial state, the description of the changes introduced, and the main conclusions obtained with the change in the procedure.

3.1 Initial Situation: "Push" approach

Before the intervention, the “push” configuration presented several inefficiencies that compromised productivity and the effectiveness of replacing products on the shelves. Likewise, several process activities presented ergonomic risks that compromise the well-being of employees in the long term.

The process illustrated on figure 1 begins with the arrival of pallets, containing mixed products, of large dimensions (up to 220cm in height) at the store warehouse. The next step involves breaking down these pallets so that the products can be subsequently sent to the shelves where they are needed. Currently, the products are distributed onto new pallets to be taken to the store based on the location of the products in their respective aisles, regardless of the actual need for replenishment of each product – a "push replenishment" approach. Since all products are transported to the store aisles without knowledge of the specific products and quantities needed, it is common for many products to be transported back to the warehouse.

Figure 1: Overview of the product flow to the store shelves

Pallet arrival and the disassembly process occur during the day while the store is open, however, most replenishment tasks are performed at night when the store is closed. This practice leads to several inefficiencies, such as increased product handling, additional transportation and storage rework, consequently decreasing the overall efficiency of the replenishment system. Additionally, restocking only after store opening hours creates windows of time during which products that could be available for sale remain inaccessible to customers. From the moment they arrive until they are replaced, products can wait approximately 15 hours.

Likewise, this system of placing products on shelves without a precise analysis of real replacement needs inhibits any possibility of standardizing processes, leading to products being transported to the store that later return to the warehouse to be stored again.

Figure 2 shows the average time of one working day for this process. Thus, an average of 28.4 man*hours is typically allocated, of which only 17.5 man*hours are spent restocking shelves. An average of 5.75 hours of unplanned breaks were observed, which mostly included help with other activities in the store and absences.

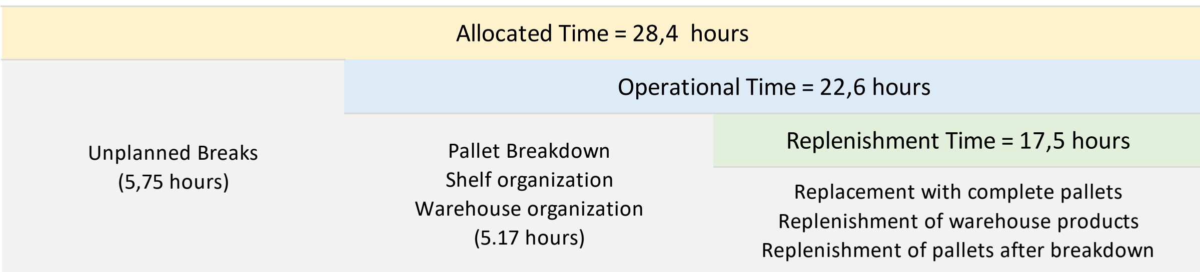

Figure 2: Labour requirements allocation

From the 22.6 man*hours considered as operational time, 5.17 man*hours are included for organization and storage activities. The time actually spent on replenishment, 17.5 man*hours, includes the replenishment of products from pallets that arrived the previous day, products that already existed in the warehouse and pallets that are taken to the store complete because they are complete pallets of the same product.

3.2 Intervention: Implementation of the "Pull" approach

The proposed solution to these issues involves transitioning to a pull replenishment model, where products are continuously restocked based on actual consumption needs. This reduces unnecessary movement and improves product availability on shelves, ensuring that only necessary items are transported from the warehouse to the store. Not only does this reduces returns to the warehouse, but it also improves product flow, leading to smoother operations and a more demand-driven approach. Likewise, we propose the introduction of a reordering point and rupture detection system to identify the real replacement needs, the proposed pull approach process is represented in figure 3.

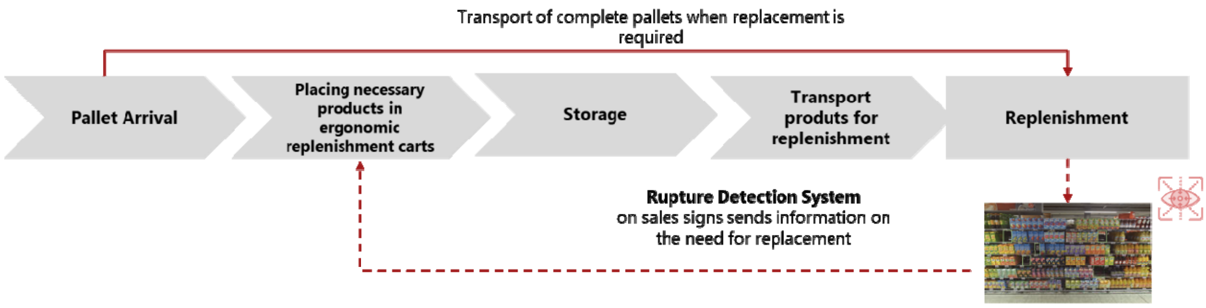

Figure 3: Flow of the proposed intervention

In the absence of a rupture detection system, as it is a technological solution that is not currently available, during the experimental period the identification of ruptures was carried out by employees in parallel with the replenishment process This solution was tested over a 5-day trial period, involving manual aisle checks to identify products needing replenishment before pallet breakdown, necessary to a pull replenishment approach. Additionally, more ergonomic replenishment trolleys were introduced to replace pallets, which required operators to perform ergonomically unfavourable movements and necessitated the use of an additional pallet jack. The introduction of ergonomic trolleys, presents itself as an ergonomically more favourable solution for the employee and was selected considering the elimination of the use of pallets and, consequently, pallet jack, as well as the elimination of the use of a trolley that is currently used to accommodate cardboard for discard. With the ergonomic trolley is possible to transport products approximately equivalent to a typical half pallet, attaching the card to one of the lower shelves, which significantly reflects efficiency gains, in addition to ergonomic improvements. In figure 4 it is possible to observe the transition from the use of three pieces of equipment to a single one that meets the same needs.

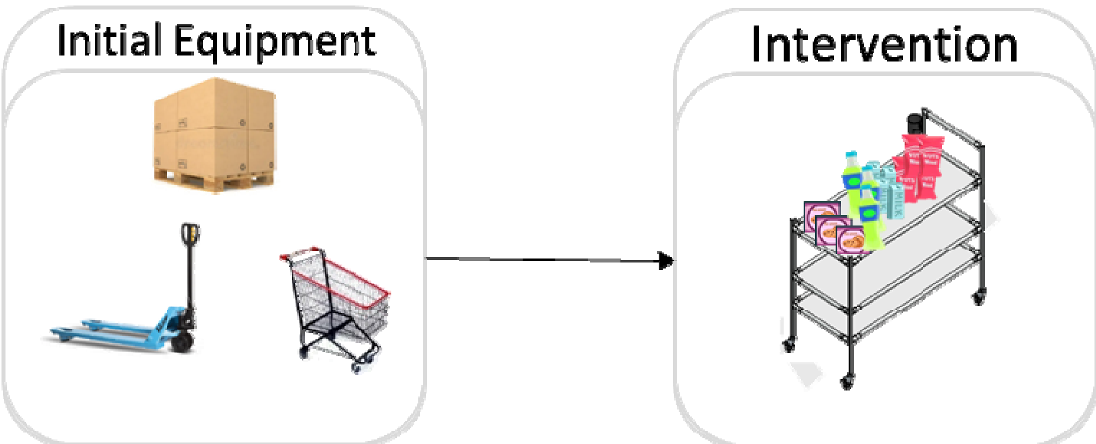

Figure 4: Improvement on transport equipment

The process of product sorting was eliminated, removing the constant decision-making burden on employees to place products on the correct pallet and eliminating the wait for replenishment after store closure. Each trolley was loaded with products in the order they were arranged on the original pallet, making it immediately operational for replenishment. Unnecessary products were transported to designated locations in the warehouse, while the rest were taken to the store. Pallets were broken down one at a time, with products immediately placed at their destination (warehouse or store shelves). Trolleys were constructed without the need for deciding product placement in-store, following routes through aisles based on the products they carried. Replenishment occurred continuously, with both open and closed-store periods, totalling 19.2 man*hours in terms of operational time as shown in figure 5.

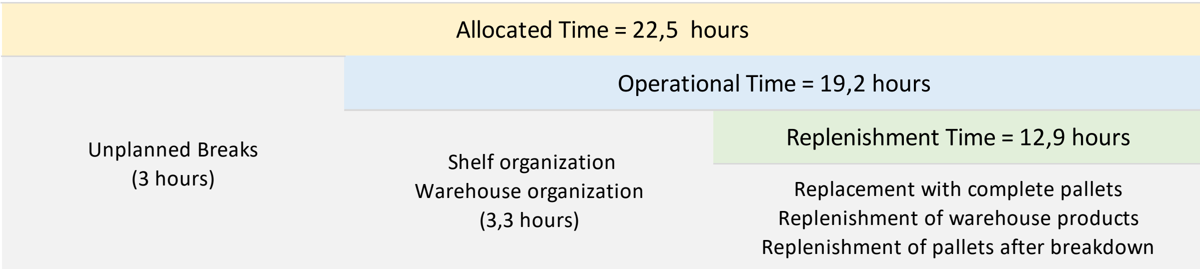

Figure 5: Labour requirements allocation at the intervention

With a total allocated time of 22.5 man*hours, 3 hours of unplanned breaks per day, 3.3 hours of organization, storage and preparation of trolleys were identified. Approximately 12.9 man*hours are used to replace products. All times represented refer to the daily average during the experimental period.

4 Discussion

The intervention of changing from a "push" to a "pull" replenishment approach resulted in significant improvements in efficiency and ergonomics. The reduction in daily man*hours from 28.4 to 19.2 demonstrates substantial savings in time and resources. This improvement can be attributed to the elimination of excessive handling and transportation, as well as the improvement of product flow based on real consumer consumption.

The introduction of ergonomic trolleys has not only improved efficiency but also provided significant improvements in ergonomics and satisfaction benefits for operators. The reduction in unfavorable movements and ease of use of the new trolleys contributed to a safer and more comfortable working environment, as evidenced by positive feedback from operators. Table 1 presents the main indicators analysed in this study.

Table 1: Performance improvements.

Indicator	Push System (Initial Situation)	Pull system (Intervention)	Return
Allocated Time (labor hours per day)	28,4	19,2	
Operational Time (labor hours per day)	22,6	16,2	-28%
Replenishment Time (labor hours per day)	17,5	12,9	-26%
Average pallet waiting time in the queue to be handled (hour/pallet)	**07h50min**	**06h40min**	**-15%**
Number of products transported to the store (average/day)	**34**	**27**	**-22%**

During the intervention it was possible to observe gains of around 28% in operational time and 26% in replenishment time. The large reduction is strictly linked to the shorter time allocated for the intervention. These indicators show the lower need for resources to execute the process, since the process of separating pallets, trips to discard cardboard and movements with pallet trucks has been eliminated. However, there are other gains to highlight, such as the number of trips to the store due to the elimination of trips associated with unnecessary products that in the initial situation were returned to the warehouse. In addition to improving efficiency, the "pull" approach also increased the availability of products on shelves during store opening hours, allowing for better interaction with customers and a faster response to their needs. The continuous presence of operators on the sales floor facilitated the detection of product shortages and timely replacement, improving the customer shopping experience.

Existing literature on Lean and Pull replenishment systems supports the conclusions of this study. Previous research indicates that applying Lean principles, such as the “pull” approach, can reduce waste and improve operational efficiency. This study contributes to this literature by providing additional empirical evidence in the food retail context.

The results have several practical implications for the food retail sector. Adopting a “pull” replenishment approach can be an effective strategy for other stores and retail chains looking to improve operational efficiency and employee satisfaction. Additionally, ergonomic improvements highlight the importance of considering operators' health and well-being when implementing process changes, which can prevent long-term workplace illnesses.

Despite the improvements observed, the implementation of the “pull” approach presented challenges, particularly related to operator training. The initial learning curve may have temporarily impacted productivity, but the results indicate that, over time, operators adapted and efficiency increased.

A limitation of the study was the relatively short testing period of 5 days. A longer observation period could provide a more detailed view of long-term impacts and help identify possible additional adjustments. Furthermore, the research was carried out in a single store, which may limit the generalization of the results.

Likewise, the way the warehouse is structured, taking into account the use of pallets, presents some challenges in storing products and identifying their location when they are needed.

5 Conclusions

This study investigated the implementation of a "pull" replenishment approach in one of the largest food retail chains in Portugal, replacing the traditional " push " system. The application of Lean principles, focused on eliminating waste and maximizing value for the customer, proved to be highly effective in improving operational efficiency and working conditions for operators.

The results demonstrated that the transition to the "pull" approach significantly reduced daily working hours of approximately 9.2 man*hours per day. This substantial improvement can be attributed to the elimination of unnecessary handling and transportation, as well as the optimization of product flow based on real consumption needs. The introduction of ergonomic trolleys has further reduced the physical effort required, resulting in less fatigue and greater operator satisfaction.

In conclusion, the implementation of the pull replenishment approach has proven to be an effective approach to improving operational efficiency, reducing waste and providing better working conditions in the food retail sector. The findings of this study provide a solid foundation for applying Lean principles in retail environments and highlight the benefits of aligning replenishment processes with actual consumer needs. Future studies with longer observation periods and in different retail contexts can help validate and expand these results, contributing to innovative and sustainable practices in the sector.

6 Acknowledgments

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Advances in Lean

Cyber Resilience and Lean in SMEs: Requirements for a Holistic Approach

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Keywords: cyber resilience, lean management, small-medium-sized enterprise, practical approach, key indicators

Abstract

The digital transformation creates a need for action. Agile and robust defense strategies are necessary to make companies resistant to complex and existence-threatening cyber attacks. In view of limited resources, the use of lean management to achieve cyber resilience can be a sensible approach, especially for small and medium-sized companies.

An integrative approach to lean management and IT security enables organizations to continuously improve their security practices, proactively identify risks and respond to cyber threats as quickly as possible.

1 Introduction

The growing threat of cyber attacks is increasing the vulnerability of SMEs (small and medium-sized enterprises) in particular. The complexity and frequency of cyber threats requires an agile and robust defense strategy to make companies resilient to potential attacks. [1] With the ongoing digital networking of operating processes, OEE (overall equipment effectiveness) is increasingly influenced by the reliability, availability, and safety of IT (information technology) and OT (operation technology), as these form the backbone of the digitized processes. When recording and analyzing data, an unstructured and overloaded data flow leads to a lack of information rather than increasing in effectiveness and reliability. In this context, the combination of cyber resilience and lean management is gaining importance as an innovative approach to organizational security.

2 Methodology

By implementing lean management techniques, SMEs can optimize their processes, reduce waste and implement and promote a culture of continuous improvement. [2] These principles can also be applied to cyber security by helping to eliminate unnecessary complexity and inefficient practices. The synergy between lean management and cyber resilience lies in the common objective: strengthening resilience through efficiency and flexibility. To prevent productivity losses, IT and OT key indicators and performance metrics must be defined as part of the application of lean management, which then flow into the evaluation of the OEE. In addition to the structured acquisition, analysis and monitoring of cyber security, an appropriate selection and prioritization of methods and measures is essential in order to reduce unnecessary complexity in the digitalized processes. An integrative approach enables organizations to continuously improve their security practices, proactively identify risks and respond to cyber threats as quickly as possible. Given limited resources and individual organizational challenges, integrating cyber resilience through lean management is a complex task.

The essential prerequisites include a clear awareness and understanding of the importance of cyber resilience and lean management at management level. [3] This includes acknowledgement of the threat landscape and a commitment to invest in the development of a security culture.

Other important aspect are the availability of expertise and resources for the implementation and operation of cyber resilience measures. [4] This can be achieved both internally through training and qualification measures and externally through cooperation with specialists or service providers. Furthermore, a comprehensive risk analysis is essential to identify the specific cyber threats and vulnerabilities of an SME. This forms the basis for designing customized cyber resilience strategies that are closely linked to the principles of lean management. Moreover successful implementation requires an agile organizational structure that makes it possible to react to new threats quickly [5] and continuous improvements. This possibly needs adjustments to existing processes and an open communication culture that enables the sharing of information and experiences. In addition, a long-term commitment and endurance are necessary to sustainably establish the integration of cyber resilience and lean in the company. This demands an iterative approach that enables continuous adjustments and optimizations to meet the constantly changing threats and challenges.

3 Conclusion

In general, cyber security and cyber resilience are not an objective in themselves. Rather, they are a prerequisite for the functionality and availability of individual resources through to complex production networks. This is where philosophy of lean management comes in. To implement this effectively, IT and OT network infrastructures should also be lean. There is a need for research how specific prerequisites and requirements can be systematized and comprehensibly recorded to successfully implement this innovative approach. The identification and fulfillment of these requirements are crucial for the success of implementing cyber resilience using lean in SMEs. By creating a robust security infrastructure, these companies can not only strengthen their resilience to cyber attacks, but also achieve long-term competitive advantages.

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Applying Lean Management: Identifying the seven types of waste in a demonstrator for automated dismantling of battery systems supported by artificial intelligence

Anwendung des Lean Managements - Sieben Arten der Verschwendung - auf einen Demonstrator für eine durch künstliche Intelligenz unterstützte, automatisierte Demontage von Batteriesystemen

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Keywords: Lean Management, Sieben Arten der Verschwendung, Demontage, Batteriesysteme, künstliche Intelligenz

Abstrakt

Um die globalen Klimaziele zu erreichen, ist die Förderung der Elektromobilität notwendig. Dies wird jedoch zu einem Anstieg der Anzahl von Batteriesystemen führen, welcher wiederum Bedenken hinsichtlich eines nachhaltigen und umweltfreundlichen Recyclings aufwirft. Die Demontage der Batteriesysteme ist eine wesentliche Voraussetzung für das Recycling oder die Wiederverwendung. Um die Kosteneffektivität und Effizienz zu erhöhen, muss die Demontage von Batterien stärker automatisiert werden. Die derzeitigen Demontagelinien zeigen die Notwendigkeit eines flexiblen Systems, das in der Lage ist, zahlreiche Varianten von Batteriemodellen zu handhaben. Das Konzept der schlanken Produktion ist entscheidend für die Schaffung eines verbesserten Demontagesystems. In diesem Artikel wird gezeigt, wie die Prinzipien des Lean Managements in ein Demontagesystem mittels künstlicher Intelligenz einfließen können. Dadurch kann eine Optimierung der Demontage von Batteriesystemen auf strukturierte Weise unterstützt werden. Der Ansatz wendet die sieben Arten der Verschwendung auf ein Konzept zur automatischen Demontage von Batteriesystemen bis auf Modulebene unter Verwendung künstlicher Intelligenz an. Der Schwerpunkt liegt dabei auf der Betrachtung der einzelnen Verschwendungsarten im Zusammenhang mit der bisherigen Demontage von Batteriesystemen. Das vorgestellte Konzept reduziert verschiedene Arten von Verschwendung. Seine Umsetzung wird durch praktische Experimente in der Zukunft untersucht.

1 Einleitung

Zur Erreichung der globalen Klimaziele und um die Dekarbonisierung des Verkehrssektors voranzutreiben, ist eine umfassende Umstrukturierung notwendig. Die Elektromobilität spielt hierbei eine entscheidende Rolle, um den Übergang von fossilen zu erneuerbaren Energien im Verkehr zu ermöglichen. Politische Maßnahmen zur Förderung der Elektromobilität wurden ergriffen und es wird prognostiziert, dass der jährliche Absatz von Elektrofahrzeugen von zwei Millionen im Jahr 2020 auf über 14 Millionen im Jahr 2030 steigen wird. Geht man von einer durchschnittlichen Batterielebensdauer von zehn Jahren und keiner weiteren Nutzung aus, müssen bis 2040 jährlich mindestens 14 Millionen Altbatterien für Elektrofahrzeuge entsorgt werden [1]. Daher ist die Wiederverwendung oder das Recycling von Elektrofahrzeug-Batteriesystemen (EFBS) von entscheidender Bedeutung. Die Demontage von EFBS bis auf Modul-, Zell- oder Materialebene ist sowohl für die Wiederverwendung gebrauchter Batterien als auch für das Recycling ihrer Materialien erforderlich. Derzeit erfolgt die Demontage von EFBS-Modellen hauptsächlich manuell, was aufgrund der Vielzahl der auf dem Markt erhältlichen Hersteller und Modelle kostenineffizient sein kann [2]. Eine effiziente Demontage ist entscheidend für den angestrebten umweltfreundlichen Übergang zur Elektromobilität.

Die Automatisierung kann eine kostengünstige, effiziente und skalierbare Lösung für Demontageprozesse bieten und dabei helfen, die steigende Zahl von Altbatterien zu bewältigen. Aufgrund der Vielfalt der Batterien ist die automatische Anpassung des Demontageprozesses jedoch eine Herausforderung. Die Durchführbarkeit der automatischen Demontage kann auch durch den Zustand der EFBS beeinflusst werden, der sich im Laufe der Zeit ändern kann. Das Lean-Konzept ist ein vielversprechender Ansatz zur Verbesserung des Demontageprozesses. Die Übertragung der sieben Verschwendungsarten des Lean-Managements auf den allgemeinen Demontageprozess von Batteriesystemen kann helfen, Optimierungsmöglichkeiten in den Prozessschritten zu identifizieren.

Ziel dieser Arbeit ist es, das Lean-Management, insbesondere die sieben Arten der Verschwendung, auf eine konzeptionelle Automatisierungslösung für ein variantenflexibles Demontagesystem für Batteriesysteme anzuwenden. Das Konzept basiert auf innovativen Digitalisierungs- und Vernetzungstechnologien, die einen digitalen Zwilling und künstliche Intelligenz (KI) zur automatischen Positionserkennung und flexiblen Systemsteuerung nutzen. Das System wird durch den Einsatz von KI mit Produktionsinformationen aus dem Lean-Management versorgt.

Dieser Artikel ist wie folgt aufgebaut: In Abschnitt 2 wird der aktuelle Stand der Lean-Ansätze im Rahmen der Digitalisierung, Industrie 4.0 und KI dargestellt. In Abschnitt 3 wird die theoretische Entwicklung erläutert, u.a. die Anwendung von Lean auf den Demontageprozess von Batteriesystemen, die Übertragung der sieben Verschwendungsarten und die Optimierungsmöglichkeiten durch KI bei der Demontage. In Abschnitt 4 werden die Einzelfallstudie und die theoretische Übertragung des Lean-Ansatzes auf ein entwickeltes Konzept zur Batterie-Demontage diskutiert. Anschließend werden die möglichen Ergebnisse analysiert und die Schlussfolgerungen in Abschnitt 5 zusammengefasst.

2 Stand der Technik

In der Literatur finden sich mehrere Ansätze, die sich mit der Anwendung von Lean Management im Rahmen der Digitalisierung, der Industrie 4.0 und dem Einsatz von künstlicher Intelligenz beschäftigen. Der folgende Abschnitt befasst sich mit diesen Methoden. Keiner der genannten Ansätze untersucht jedoch die sieben Arten der Verschwendung, die mit der Demontage von Batteriesystemen verbunden sind.

KI-Algorithmen können in industriellen Prozessen eingesetzt werden, um die sieben Verschwendungsarten zu identifizieren. Ahmed et al. [3] analysierten die Verbindung zwischen Lean-Praktiken und der Implementierung von KI, die sich in verschiedenen Branchen positiv auswirkt, z. B. bei der Qualitätskontrolle in der Fertigung und der vorausschauenden Wartung im Automobilbereich. Beide Beispiele tragen zur Reduzierung der zwei Arten der Verschwendung „Defekte“ und „Warten“ bei. Darüber hinaus können Bildverarbeitungssysteme zur automatischen Erkennung beschädigter Teile eingesetzt werden, wodurch Verschwendung in Form von verschwendeten Arbeitsstunden und Ressourcen reduziert wird [4].

Chatzopoulos et al. [5] erwähnen die Überschneidung von Digitalisierung und Lean Management in industriellen Anwendungen und betonen die Bedeutung der Integration dieser Ansätze für die Prozessverbesserung. Die Autoren betonen, dass der Versuch, ineffektive oder ineffiziente Systeme ohne vorherige Lean-Optimierung zu digitalisieren, zu erfolglosen Ergebnissen führen kann. Folglich wird empfohlen, die Prinzipien des Lean Managements zur Steigerung des Kundennutzens und der betrieblichen Effizienz in den Vordergrund zu stellen, bevor Digitalisierungsinitiativen in Angriff genommen werden. Durch die anfängliche Optimierung von Arbeitsabläufen und die Beseitigung von Verschwendung durch Lean Management können Unternehmen eine solide Grundlage für eine erfolgreiche digitale Transformation schaffen. Dieser ganzheitliche Ansatz stellt sicher, dass die Digitalisierungsbemühungen auf effektiven Prozessen aufbauen, was letztlich zu einem verbesserten Kundenerlebnis und einem höheren Unternehmenswert führt.

Helmold [6] erörtert die Integration von Lean-Management-Prinzipien mit aufkommenden digitalen Technologien und konzentriert sich dabei insbesondere auf die Überschneidung von Lean-Management und KI. Die Einbindung digitaler Lean-Management-Tools umfasst verschiedene Funktionen wie autonome Roboter, virtuelle Produktions- und Lieferketten, Lean-Simulationen, Systemintegration, Internet der Dinge, Cybersicherheit, Cloud Computing, additive Fertigung, Augmented Reality und Big Data. Diese Funktionen ermöglichen eine verbesserte betriebliche Effizienz und Effektivität in verschiedenen Bereichen der Unternehmensprozesse. Durch den Einsatz dieser digitalen Tools können Unternehmen ihre Abläufe rationalisieren, Verschwendung minimieren und den Kundennutzen maximieren, um so ihre Leistung und Wettbewerbsfähigkeit nachhaltig zu verbessern.

Najafi et al. [7] integrieren Lean-Methoden mit Industrie 4.0 und stellen neue Tools wie Heijunka 4.0 und Kanban 4.0 vor. Der Artikel erforscht das Potenzial der Integration von Blockchain und KI in Six Sigma. Algorithmen des maschinellen Lernens werden zur Identifizierung von Ursachen in Six-Sigma-Projekten eingesetzt. Der Übergang vom traditionellen Six Sigma zum Data Science Six Sigma erfordert die Zusammenarbeit zwischen Six Sigma-Experten und Datenwissenschaftlern.

Gupta et al. [8] erläutern, wie maschinelles Lernen im Kontext von Lean Six Sigma eingesetzt werden kann, wo es auf der Grundlage großer Datensätze Ergebnisse identifizieren und vorhersagen kann. Dies ist für die Analyse- und Verbesserungsphasen in Lean Six Sigma entscheidend.

Bajpai und Bajpai [9] erwähnen, dass KI-gesteuerte Systeme für die Bestandsverwaltung die Verfolgung von Lager- und Produktionsbeständen automatisieren. Die prädiktiven Analysefähigkeiten der KI ermöglichen präzise Prognosen, die Überproduktionsabfälle effektiv minimieren und die Produktverfügbarkeit garantieren. Transport-Verschwendung kann mit Hilfe von KI durch die Optimierung und Automatisierung logistischer Abläufe reduziert werden, z. B. durch den Einsatz von autonomen fahrerlosen Transportfahrzeugen mit Fuzzy-Logik und heuristischen Methoden zur Routenoptimierung [10].

Mortada et al. [11] integrierten KI und Lean Management durch die Entwicklung eines Fuzzy-Logik-Modells, um Beschwerden über Qualitätsmängel bei Produkten zu vermeiden. Durch die Kombination von Lean-Tools und dem Fuzzy-Logik-Modell kann entschieden werden, welche Mängel auf der Grundlage ihres Risikos, Kundenreklamationen zu verursachen, zuerst angegangen werden müssen. Die Lean-Management-Tools haben bei der Reduzierung dieser Mängel geholfen.

Jobin et al. [12] führten ein neuronales Netzmodell ein, das Ergebnisse für verschiedene Aspekte der schlanken Produktion vorhersagt. Sie erreichten dies, indem sie Antworten auf Fragen zum Bekanntheitsgrad von Lean-Praktiken, zum Engagement der Mitarbeiter, zur Lean-Technologie und zur Unternehmensleistung verwendeten. Das Modell verwendet diese Antworten als Eingaben und zielt auf die manuell beschrifteten Werte ab. Diese Methode zielt darauf ab, die organisatorische Leistung in der schlanken Fertigung zu verbessern, indem die Effektivität von Strategien vorhergesagt und Bereiche für Verbesserungen und Verschwendungsreduzierung ermittelt werden.

3 Theoretische Entwicklung

Der derzeitige Stand der Technik zeigt, dass die sieben Arten der Verschwendung bei der Demontage von Batteriesystemen noch nicht genauer betrachtet wurden. In dieser Analyse werden die Verschwendungsarten aus dem Lean Management auf den Demontageprozess von EFBS angewandt und anschließend auf ein individuelles Konzept übertragen. Wie in der Einleitung beschrieben, bietet die Automatisierung der Demontage von EFBS die Möglichkeit, die steigende Anzahl von Altbatterien zu verwalten und einen effektiven Produkt- und Rohstoffkreislauf zu schaffen. Durch den Einsatz von KI kann der Demontageprozess flexibel an eine Vielzahl von Batterietypen angepasst werden. Auch der Demontageprozess selbst kann mit Hilfe von KI kontinuierlich optimiert werden, um das Gesamtsystem effizienter zu gestalten [13]. Um diese Optimierungsansätze zielgerichtet und systematisch zu gestalten, ist es ratsam, sie an einem bestimmten Konzept auszurichten. Eine mögliche Methode, um Prozesse effizienter und produktiver zu gestalten, ist das Lean Management [14].

4 Lean Management innerhalb der Batterie-Demontage

Lean Management ist eine Managementphilosophie, die darauf abzielt, die Verschwendung zu minimieren und den Wert für den Kunden zu maximieren. Sie wurde ursprünglich von Toyota entwickelt und hat sich seitdem in verschiedenen Branchen und Organisationen verbreitet [15]. Im Kern konzentriert sich das Lean Management auf die Schaffung von Werten aus der Sicht des Kunden, indem es sich auf die Beseitigung von Verschwendung konzentriert. Verschwendung ist definiert als alles, was nicht direkt einen Wert für den Kunden schafft. Dabei kann es sich um unnötige Prozessschritte, übermäßige Bestände, Wartezeiten, Mängel oder andere ineffiziente Praktiken handeln [16].

Ein zentraler Ansatz im Lean Management ist das Konzept der sieben Verschwendungsarten. In Tabelle 1 sind die verschiedenen Arten von Verschwendung nach Hines und Taylor [17] aufgeführt.

Tabelle 1: Sieben Arten der Verschwendung [17].

Verschwendungsart	**Erläuterung**
Transport	Unnötige Bewegung von Materialien oder Produkten zwischen verschiedenen Standorten. Dies kann zu zusätzlichen Kosten und möglichen Schäden führen.
Lagerbestand	Die Lagerung von Materialien oder Produkten, die über den unmittelbaren Bedarf hinausgehen. Dies führt zu versteckten Kosten wie z. B. Lagerkosten.
Bewegung	Übermäßige oder unnötige Bewegungen während der Arbeitsprozesse, die wiederum Zeit und Energie verschwenden.
Warten	Zeit, die durch das Warten auf Materialien, Informationen oder Arbeitsanweisungen verloren geht.
Überproduktion	Die Produktion von mehr Produkten oder Dienstleistungen als benötigt. Dies führt zu erhöhten Lagerbeständen und damit zu unnötigen Kosten.
Überarbeitung	Korrekturen oder Nacharbeiten an Produkten oder Dienstleistungen aufgrund von Fehlern oder Qualitätsproblemen, die vermieden werden konnten.
Defekte	Fehler in Prozessen oder Produkten führen zu Mehraufwand, Nacharbeit und potenziell negativen Auswirkungen auf die Kundenzufriedenheit.

Diese Arten von Verschwendung können die Effizienz einer Organisation erheblich verringern und die Kosten erhöhen. Durch die Identifizierung und Beseitigung dieser Verschwendungen strebt das Lean Management danach, Prozesse schlanker, effizienter und wertschöpfender zu gestalten [17].

5 Sieben Arten der Verschwendung innerhalb der Batterie-Demontage

5.1 Transport

Dieser Ansatz zielt darauf ab, die Kosten der intralogistischen Prozesse zu minimieren und gleichzeitig die Lieferzeiten durch die Vermeidung von Engpässen zu optimieren. KI kann dabei helfen, indem sie die effizientesten Transportrouten berechnet [18].

Bei der externen Logistik können mehrere Faktoren berücksichtigt werden, darunter die Entfernung zwischen den Standorten, die Transportkapazität, Echtzeit-Verkehrsdaten und die Transportkosten. Die KI analysiert diese Daten, um Engpässe zu erkennen und alternative Routen vorzuschlagen, die den Transport effizienter machen. Darüber hinaus kann die KI mithilfe von Prognosemodellen zukünftige Verkehrsmuster vorhersagen und entsprechend planen. Dies ermöglicht eine vorausschauende Optimierung des Transportprozesses, um Engpässe zu vermeiden und die Lieferzeiten zu minimieren.

KI kann auch zur Verbesserung von Intralogistikprozessen eingesetzt werden, indem beispielsweise der Transport zwischen den Demontagezellen effizienter gestaltet wird, Routen optimiert und Hindernisse automatisch erkannt und umgangen werden.

5.2 Lagerbestand

Durch die Überwachung des Materialflusses in Echtzeit und die Vorhersage künftiger Batterietypen und Lieferketteninformationen kann KI dazu beitragen, den Materialfluss entsprechend zu steuern und überschüssige Bestände zu vermeiden. Dies führt zu einer optimierten Nutzung der Ressourcen [18].

RFID- oder Barcode-Systeme können in den Prozess integriert werden, um die Überwachung und Verwaltung des Materialflusses zu verbessern. Mit diesen Systemen können Batterien und Komponenten eindeutig identifiziert und während des gesamten Prozesses verfolgt werden. Durch die Integration dieser Systeme kann KI den Standort, die Verfügbarkeit und den Fluss von Materialien in Echtzeit verfolgen und verwalten.

Auf der Grundlage der analysierten Daten und Prognosen kann die KI Entscheidungen darüber treffen, wie der Materialfluss optimiert werden kann, um einen überschüssigen Lagerbestand zu vermeiden. Dies kann die Anpassung der Produktion an die aktuelle Nachfrage, die Optimierung der Lagerbestände oder die Verbesserung der Prozesse in der Lieferkette umfassen.

5.3 Bewegung

Die Reduzierung unnötiger Bewegungen während der Batteriezerlegung durch eine KI, kann durch die Anwendung von Methoden des maschinellen Lernens und Optimierungsalgorithmen erreicht werden [19]. Diese Methoden beruhen auf der Analyse historischer Demontagedaten und Echtzeit-Sensordaten, um effiziente Demontagepfade zu erlernen und vorzuschlagen.

Die Analyse historischer Daten identifiziert Muster und Trends, die auf ineffiziente Bewegungen oder suboptimale Demontagepfade hinweisen. Echtzeit-Sensordaten von Sensoren, die während der Demontage angebracht werden, liefern kontinuierlich Informationen über die Position und den Zustand der zu demontierenden Batterien. Diese Daten können von der KI verwendet werden, um den aktuellen Fortschritt des Demontageprozesses zu überwachen und gegebenenfalls Anpassungen vorzunehmen. Anhand der gesammelten Daten kann die KI lernen, welche Bewegungen während der Demontage am effizientesten sind. Mithilfe von Optimierungsalgorithmen können die Demontagepfade kontinuierlich verbessert werden, um die Effizienz zu maximieren.

Einerseits könnte die KI zur Steuerung bestehender Roboter eingesetzt werden, um die Bewegungen während der Demontage zu optimieren und automatisch anzupassen. Dies geschieht durch eine präzise Steuerung der Roboter, um unnötige Bewegungen zu minimieren und den Demontageprozess zu beschleunigen. Andererseits könnte KI auch eingesetzt werden, um die intralogistischen Prozesse für die Zu- und Abfuhr der Batterien zur und von der Demontageanlage und der einzelnen demontierten Teile aus der Anlage zu optimieren.

5.4 Warten

Um Wartezeiten bei der Demontage von EFBS zu vermeiden, kann KI in der Produktionsplanung eingesetzt werden, um zu ermitteln, wann welcher Batterietyp demontiert werden muss, um den gesamten Demontageprozess mit möglichst kurzen Stillstandzeiten der Anlage zu planen [18].

Auch während des eigentlichen Demontageprozesses kann KI eingesetzt werden, um Wartezeiten durch die Optimierung einzelner Prozessschritte zu minimieren, Werkzeugwechsel durch eine intelligente Abfolge von Prozessschritten zu minimieren und den gesamten Demontageprozess flexibler und effizienter zu gestalten. Auch der KI-gestützte Ein- und Ausgangstransport von EFBS oder entsprechenden Einzelteilen zur und von der Demontageanlage kann intralogistische Prozesse optimieren. Dies wirkt sich wiederum positiv auf die Wartezeiten der gesamten Demontageanlage aus.

5.5 Überproduktion

Auch bei der Demontage von Batterien kann KI helfen, Überproduktion zu vermeiden. Mit Hilfe von Algorithmen des maschinellen Lernens lassen sich genaue Bedarfsprognosen erstellen. Diese Prognosen können dann zur Steuerung des Demontageprozesses verwendet werden, um eine Überdemontage bestimmter Batterietypen zu vermeiden, z. B. wenn der gesamte Lagerplatz eines Lkws für die demontierten Teile dieses Batterietyps bereits für den Transport verwendet wird oder wenn historische Daten darauf hindeuten, dass in bestimmten Phasen eine geringere Nachfrage nach einigen demontierten Komponenten besteht.

Durch die kontinuierliche Anpassung des Demontageprozesses auf der Grundlage von Prognosemodellen und Echtzeitdaten, kann die KI die Demontage von EFBS genau auf die aktuelle Nachfrage nach Komponenten oder Rohstoffen abstimmen. Dies minimiert das

Risiko einer Überproduktion und führt zu einer optimierten Ressourcennutzung sowie zu einer Verringerung von Lagerbeständen und Verschwendung.

5.6 Überarbeitung

KI kann bei der Demontage von EFBS ebenfalls helfen, unnötige Prozessschritte zu reduzieren. Durch eine kontinuierliche Überwachung des Prozesses können Optimierungspotenziale identifiziert und automatisch umgesetzt werden, indem beispielsweise unnötige Schritte oder Bewegungen eliminiert werden.

Darüber hinaus können Bildverarbeitungsalgorithmen eingesetzt werden, um Fehler oder Abweichungen im Demontageprozess frühzeitig zu erkennen. Dadurch ist es möglich, das EFBS auszuschleusen oder den Prozess abzubrechen, bevor weitere unnötige Demontageschritte daran vorgenommen werden.

5.7 Defekte

Durch die kontinuierliche Überwachung und Analyse von Daten in Echtzeit ermöglicht der Einsatz von KI eine proaktive Fehlererkennung und -behebung während des EFBS-Demontageprozesses. Dies trägt dazu bei, die Sicherheit während der automatischen Demontage zu gewährleisten und die Gesamteffizienz des Demontageprozesses zu erhöhen [20].

KI, die auf Algorithmen zur Erkennung von Anomalien basiert, kann zur Minimierung von Fehlern während der EFBS-Demontage eingesetzt werden. Sie kann ungewöhnliche Muster oder Abweichungen von der Norm erkennen und sofortige Maßnahmen vorschlagen. Die KI kann kontinuierlich Daten aus verschiedenen Quellen analysieren, einschließlich der während des Demontageprozesses angebrachten Sensoren und historischer Daten aus früheren Demontagevorgängen. Zu diesen Daten können Kamerabilder, Prozesstemperaturen oder -drücke gehören. Wenn eine Anomalie erkannt wird, schlägt die KI sofort Maßnahmen vor, um das Fehlerrisiko zu minimieren. Dies kann die automatische Anpassung von Prozessparametern oder die Unterbrechung des Demontageprozesses und die Alarmierung des Bedienpersonals umfassen.

Fallstudie

Die Anwendung der sieben Verschwendungsarten aus dem Lean Management ist generell auf viele Demontageprozesse übertragbar, auch auf die automatisierte, durch künstliche Intelligenz unterstützte Demontage von EFBS. Dazu muss das gesamte System betrachtet werden und die allgemeine Struktur und der Prozessablauf des Konzepts vorgegeben werden. In diesem Zusammenhang werden dann die sieben Verschwendungsarten auf das beschriebene Konzept angewendet.

6 Demonstrator für die künstliche Intelligenz gestützte automatisierte Demontage von Batterie-Systemen

Das Konzept für ein intelligentes Demontagesystem, das den Demontageprozess von EFBS automatisieren soll, integriert bestehende Technologien mit Ansätzen aus der Robotik, optische Detektionssysteme und künstliche Intelligenz. Ein digitaler Zwilling wird für eine umfassende Prozessanalyse und -simulation eingesetzt. Das Konzept sieht vor, Demonstratoren und Dummy‘s zu entwerfen und zu implementieren, die die entsprechenden EFBS repräsentieren, sie nahtlos in den digitalen Zwilling und die KI zu integrieren und die automatische Demontage von EFBS zu ermöglichen.

Um die große Anzahl von Schritten im Demontageprozess adäquat zu berücksichtigen, werden zwei unterschiedliche Demonstrator-Systeme eingesetzt. Ein System ist für die Trennung der Batteriegehäuseverbindungen bis auf Modulebene ausgelegt, während das andere System für die Demontage des Batteriemoduls und der zugehörigen Komponenten verwendet wird. Um die Vielfalt der im Recyclingprozess verwendeten EFBS realistisch zu simulieren, werden drei verschiedene Batterie- Dummy‘s eingesetzt. Diese Dummy‘s sind realitätsnah, aber frei von gefährlichen Stoffen, was dazu beiträgt, Risiken wie auslaufende gefährliche Stoffe oder Kosten für den sicheren Transport der erforderlichen Anzahl von EFBS zu vermeiden. Zum anderen bietet der Demontagesystem-Demonstrator Vorteile wie die Konstruktion reversibler Verbindungen für die Wiederholung von Versuchsreihen und eine versuchs- und demonstrationsorientierte Dimensionierung des Systems und der Dummy‘s. Darüber hinaus ermöglichen die eingesetzten Dummy‘s die Erforschung innovativer Ansätze für den Einsatz von flexiblen Werkzeugen und typflexiblen Werkstückträgern.

Das Konzept wurde entwickelt, um zwei Demontagesysteme in einen Materialfluss zu integrieren. Ein Dummy, der mit dem fahrerlosen Transportsystem kompatibel ist, wird automatisch aus einem Hochregallager auf eine Transportrollenbahn transportiert. Das fahrerlose Transportsystem setzt den Dummy dann auf die Transportrollenbahn, die ihn zu einem nah gelegenen Industrieroboter transportiert. In diesem Stadium werden die Entschraubungsvorgänge von dem ersten Demonstrator-System durchgeführt, gefolgt von dem Schritt der Entnahme durch das andere Demonstrator-System. Optische Sensoren, die mit dem Kamerasystem des Roboters verbunden sind, erkennen die genaue Position und den Batterietyp. Die künstliche Intelligenz identifiziert dann die Position und die Anschlusspunkte der verschiedenen Batterieelemente, einschließlich Steckverbindungen, Kabel, Klebefolien und Batteriemodule. Die KI vergleicht die erfassten Daten des Dummy‘s, wie z. B. Modelltyp und Anordnung der Komponenten mit einer bestehenden Datenbank.

Sind in einem Szenario die für die Demontage erforderlichen Daten vorhanden, gibt die KI dem Roboter den entsprechenden Ablauf der Demontage vor. In einem anderen Szenario, wenn für diese Anordnungskonstellation des Dummy‘s noch keine Daten vorhanden sind, muss die KI eine neue Demontagestrategie auf Basis der optisch erfassten Daten entwickeln und speichern. Der mit einem Werkzeugwechselsystem ausgestattete Roboter demontiert die Komponenten des Dummy‘s bis auf Modulebene und legt sie anhand der gewonnenen Daten auf einem angrenzenden Ablagetisch ab. Das leere Gehäuse des Batterie-Dummy‘s wird dann am Ende des Prozesses vom fahrerlosen Transportsystem aus der Anlage in ein Hochregallager transportiert.

Anhand dieses Konzepts lassen sich die Vorteile der sieben Verschwendungsarten aus dem Lean Management, die in diesem Konzept angewandt und diskutiert wurden, mit bisherigen Demontagekonzepten vergleichen.

7 Anwendung der Sieben Arten der Verschwendung auf den Demonstrator

Die theoretische Anwendung von Verschwendungsarten aus dem Lean Management auf das im vorangegangenen Kapitel 6 beschriebene Konzept führt zu einigen verbesserten prozessbezogenen Ansätzen für die Demontage von Batteriesystemen. Die im Konzept eingesetzte künstliche Intelligenz soll durch Lean-Ansätze informiert werden und kann auf dieser Basis entsprechende Lean-Strukturen umsetzen. Die KI-basierte Prozesssteuerung des neu entwickelten Demontagesystems entspricht damit dem wesentlichen Lean-Management-Ansatz zur Nachahmung der automatisierten Demontage. Die KI wird eingesetzt, um den im Konzept verwendeten Dummy zu erkennen und die Demontagesequenz zu bestimmen bzw. zu erstellen. Dieser automatisierte Prozess reduziert Wartezeiten und Überproduktionen. Durch die Erstellung eines digitalen Zwillings, kann der zu untersuchende Prozess im Konzept vorab simuliert und untersucht werden. Dies ermöglicht eine frühzeitige Fehlererkennung, wodurch die Anzahl der Fehler minimiert wird.

Im Folgenden werden die sieben Verschwendungsarten (Transport, Lagerbestand, Bewegung, Warten, Überproduktion, Überbearbeitung und Defekte) in Bezug auf das konzeptionell vorgestellte Demonstrator-System untersucht.

7.1 Transport

Innerhalb des Demonstrator-Systems befinden sich die Haupttransportwege zwischen dem Hochregallager und der Transportrollenbahn. Der Dummy wird von einem fahrerlosen Transportsystem transportiert. Ein intelligentes Steuerungssystem mit KI, kann diese Transporte über Ein- und Ausgangssignale auslösen. Diese Steuerung orientiert sich an der Verweildauer des Dummy‘s im Demontageprozess und den schnellstmöglichen Wegen zwischen den Einheiten. Daraus resultiert ein automatisierter, transportoptimierter Materialfluss innerhalb der Demonstrator-Anlage.

7.2 Lagerbestand

Auch die vorhandenen Bestände werden durch die intelligente Steuerung mittels KI in und aus der Demontageanlage überprüft. Die zu Beginn des Prozesses gelagerten Batterie-

Dummy‘s werden über Signale schnellstmöglich zur Demontage freigegeben. Die demontierten Komponenten des Dummy‘s werden nach dem Demontageprozess für die stoffliche Verwertung vorbereitet, was in diesem Konzept nicht weiter betrachtet wird.

7.3 Bewegung

Durch die Integration eines digitalen Zwillings können ineffiziente Bewegungen innerhalb des Gesamtkonzeptes herausgefiltert werden. Durch eine Vorsimulation des Prozesses können Arbeits- und Teilprozessabläufe analysiert und unnötige Bewegungen eliminiert werden.

7.4 Warten

Durch die Erstellung eines digitalen Zwillings, der mit der KI vernetzt sowie das gesamte Demonstrator-System widerspiegelt, können entsprechende Echtzeit-Datenanalysen integriert werden. So kann jeder Prozessschritt mit Daten überwacht werden. Dadurch können Wartezeiten zwischen den Prozessschritten minimiert und der gesamte Materialfluss optimiert werden. Die intelligente Sequenzierung der einzelnen Demontageschritte durch die KI reduziert die Anzahl der Werkzeugwechsel zwischen den Prozessschritten.

7.5 Überproduktion

Der gesamte Demontageprozess wird von einer KI gesteuert, die mit Hilfe eines Kamerasystems die jeweiligen Dummy‘s erkennt, die Struktur analysiert und die optimale Demontagestrategie entwickelt. Die KI erkennt, welche Komponenten zuerst demontiert werden müssen und welches Werkzeug für den jeweiligen Demontageprozess benötigt wird. Des Weiteren steuert sie den Industrieroboter entsprechend der Struktur der erstellten Prozesssequenz, dieser demontiert die Komponenten und legt sie sortiert auf einem Ablagetisch ab. So wird sichergestellt, dass keine Teile des Batterie- Dummy‘s unnötig gehandhabt werden.

7.6 Überbearbeitung

Einzelne Prozessschritte können sowohl im Vorfeld als auch durch Experimente mittels Simulation oder Steuerung des digitalen Zwillings optimiert werden. Dazu werden Echtzeitdaten jedes Prozessschrittes mit dem digitalen Zwilling erzeugt, ausgewertet und optimiert. Die ausgewerteten Daten bzw. Prozessschritte werden dann an die integrierte KI kommuniziert und angewendet. Überflüssige Prozessschritte werden identifiziert und eliminiert.

7.7 Defekte

Durch die Integration des digitalen Zwillings, kann eine Fehleranalyse vor der Inbetriebnahme des Systems durchgeführt werden. Das bedeutet, dass vorhandene Defekte frühzeitig erkannt und vor der Implementierung vermieden werden können. Defekte, die an den entsprechenden Dummy‘s vorhanden sind, können durch die KI und das angebundene Kamerasystem erkannt werden, dadurch können vor dem eigentlichen Demontageprozess präventive Maßnahmen eingeleitet werden.

8 Diskussion

In diesem Beitrag wird ein theoretischer Ansatz für den Einsatz von Lean-Management-Methoden vorgestellt, um weitere Optimierungsmöglichkeiten für ein System zu identifizieren, das KI zur automatischen Demontage von EFBS einsetzt. Ziel der Anwendung der sieben Verschwendungsarten auf das erstellte Demontagesystem ist es, die betrachteten Prozesse zu verbessern und das Einsparungspotenzial in den definierten Bereichen zu erhöhen. Durch die konzeptionelle Identifizierung und Anwendung der Verschwendungsarten aus dem Lean Management auf das neu entwickelte Konzept zur automatisierten Demontage von EFBS wird ein System betrachtet, das in dieser Form in der Literatur noch nicht untersucht wurde. Die vorhandene Literatur befasst sich hauptsächlich mit der allgemeinen Übertragung von Lean-Prinzipien auf Prozesse im Rahmen der Digitalisierung und Industrie 4.0, wobei die sieben Verschwendungsarten nicht spezifisch auf ein bestimmtes System übertragen werden. Die theoretische Übertragung der Verschwendungsarten auf das neu entwickelte Demontagekonzept für Batteriesysteme bildet somit einen neuen individuellen Ansatz für die praktische Umsetzung der Lean-Prinzipien mittels künstlicher Intelligenz. Das Lean-Konzept soll somit in der zukünftigen praktischen Umsetzung mittels KI optimiert und weiterentwickelt werden. Durch eine entsprechende Datenanalyse der Prozessschritte mittels Simulation und die vorherige Ergänzung des Systems um einen digitalen Zwilling können mit Hilfe der KI-Programmierung weitere Schwachstellen im Demontageprozess aufgedeckt und anschließend im Sinne einer schlanken Produktion beseitigt werden. Durch die Integration von Informationen aus dem Lean Management kann die KI entsprechende Trainingsdatensätze zur Verbesserung der Prozesse generieren.

9 Zusammenfassung und Ausblick

Die steigende Zahl der zugelassenen Elektrofahrzeuge führt zu einer entsprechenden Zunahme der Altfahrzeuge und damit auch der EFBS. Um Nachhaltigkeit und grüne Mobilität zu erreichen, ist es unerlässlich, diese Batterien zu zerlegen und ihre einzelnen Komponenten wiederzuverwenden oder zu recyceln. Daher ist die Automatisierung des Demontageprozesses von EFBS unerlässlich. Dabei bietet die künstliche Intelligenz eine Lösung für die Verwaltung verschiedener EFBS-Modelle und die Schaffung eines flexiblen, automatisierten Demontageprozesses. Die Integration von Lean-Ansätzen in diesen KI-gestützten Prozess kann dessen Effektivität und Ressourceneffizienz erhöhen.

In diesem Beitrag wird die konzeptionelle Anwendung von Lean Management, insbesondere der sieben Arten der Verschwendung, auf ein neuartiges Demonstrator-System zur Demontage von Batteriesystemen vorgestellt. Ziel des neuen Demontagekonzepts ist die Erforschung neuer Techniken und Verfahren für die Demontage von Batteriesystemen sowie die automatisierte Lösung und Verbesserung der Prozessschritte. Durch die Integration von künstlicher Intelligenz und den Einsatz eines digitalen Zwillings innerhalb des neu entwickelten Konzepts können einige Punkte der theoretisch übertragenen sieben Verschwendungsarten, aus der allgemeinen bisherigen Demontage von Batteriesystemen unter dem Informationstransfer des Lean-Ansatzes verbessert werden. Das bedeutet, dass einzelne Prozessschritte vorab simuliert und untersucht, Verschwendungsarten identifiziert und dann eliminiert werden können.

In naher Zukunft wird der Demonstrator hardwareseitig aufgebaut und mit einem noch zu entwickelnden und zu trainierenden KI-System verbunden. Die Anwendung von Lean-Methoden bei der automatisierten KI-gesteuerten Demontage von EFBS kann in der Praxis getestet und optimiert werden.

Offenlegung von Interessen

Die Autoren haben keine konkurrierenden Interessen zu erklären, die für den Inhalt dieses Artikels relevant sind.

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Lean: what does it mean?

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Keywords: lean, lean thinking, lean production, lean manufacturing

Abstract

Nowadays, we can see that there is a great deal of carelessness and sloppiness in the use of the term Lean. In fact, the term is often used indiscriminately and inappropriately, associating it with other terms/expressions, just because someone thinks they can do it. One of the problems that results from this light-heartedness is that many problems end up being pointed at the implementation of Lean approaches in some companies/organisations, when in reality these approaches do not comply with fundamental Lean principles and concepts, i.e. they are not Lean at all. Therefore, Lean is wrongly being blamed for problems/disadvantages that it does not actually has. This is the context that motivates the development of this article, which will seek to clarify the meaning of the term Lean so that it is possible to understand whether a given implementation/approach should be considered Lean or not. Regarding methodology, the work is based in a detailed bibliographical review, not only of what are considered to be reference books (e.g. on the Toyota Production System, Lean Production/Manufacturing/Thinking, and the Toyota Way), but also of recent scientific articles, in order to clarify (i) the meaning of the term Lean as originally defined and (ii) the evolution of that same meaning over time, all duly structured in terms of the principles and concepts involved. This research has led to three hypotheses for interpreting the term Lean and the work carried out to analyse them points to one of these hypotheses as being, in our opinion, the most appropriate.

1 Introduction

It has become increasingly evident to us that within the realm of production, the term *Lean* undergoes vast variations of interpretation among various authors, speakers, academics, and professionals. Each individual freely shapes this term according to his/her understanding or intuition, and it seems to be widely accepted (a bit like the term *Intelligent* (or *Smart*), which is nowadays associated, in a completely erroneous way, with many systems/tools/applications just because it is an appealing buzzword). There is a prevailing sense that everyone can impart their personal spin on the true *Lean* and associate it to whatever concepts, principles, or tools they prefer. Expressions such as *Lean concepts*, *Lean principles*, or *Lean tools* are often used as if their meanings were universally understood and implicit. The issue becomes particularly evident with the designation *Lean tools*, so frequently referred. Many of the tools labelled as *Lean tools* have been utilized in other contexts previously, and some of them may not align with the essence of *Lean* philosophy at all (we will develop this issue later in this article). To expand a little on this topic, let's say that, in reality, tools are essentially practical solutions developed in specific contexts to materialize a certain concept or principle. To illustrate this perspective, consider *Kanban*: it serves as a tool for regulating pull production in simple and consistent sequential production scenarios, but its effectiveness diminishes in complex and volatile production environments. Other tools exist or need to be developed to be effective in guaranteeing pull flow in more complex production realities. For those tools that are in line with the vision or *True north* of *Lean*, a more fitting terminology might be to describe them as "tools aligned with the philosophy of *Lean*". This shift in language clarifies the alignment of the tools with the overarching principles of *Lean thinking*.

When the Massachusetts Institute of Technology (MIT) researchers coined the expression *Lean production*, they described it as the embodiment of how Toyota organized and managed its operations at that time, i.e., the Toyota Production System (TPS). There seems to be little doubt about this. This is very well documented by Krafcik (1988) and Womack et al. (1990). However, the current challenge lies in grasping the contemporary significance of *Lean*. Is it the same as it was defined in the eighties, is it the same as Toyota Way now, or is it something else (Figure 1)?

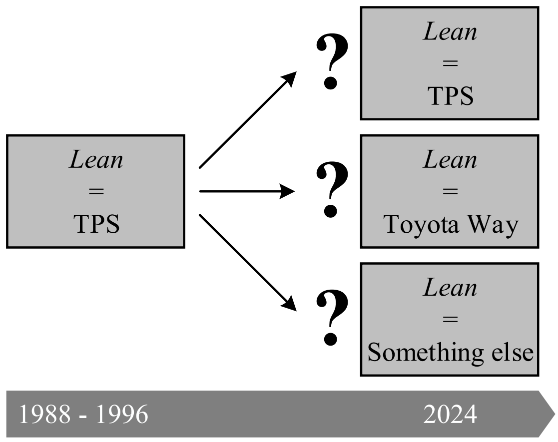

Figure 1: What is the meaning of *Lean* in 2024?

In other words, have the concepts and principles of *Lean* remained unchanged since its inception in the 1980s, closely mirroring Toyota's methodologies of that era? Should *Lean* today adhere strictly to the contemporary practices of Toyota? Or has it diverged and evolved independently over time?

This article aims to find an answer to this quest. It will start by including the meaning that was given to the term *Lean* when it was first introduced, showing evidence of that. It will then refer to the arguments and the respective bibliographic sources, to present what we believe to be the current meaning of *Lean*. We aim to provide clarity by presenting the essential arguments regarding the understanding of *Lean* and its associated concepts and principles. Additionally, we also want to discuss, with solid argumentation, that continuous improvement is not the same as *Lean* as many authors suggest.

The article is organized as follows. After the current introduction, section 2 describes the adopted methodology. Section 3 elaborates on the meaning of *Lean* when the term was coined in 1988, including the associated principles and concepts. Section 4 elaborates on the meaning of *Lean* in 2024, considering three hypotheses (Figure 1). The findings are described and discussed in section 5, including the current meaning of *Lean* in our perspective. Lastly, section 6 outlines the final considerations.

2 Methodology

The methodology supporting this study is represented in the structure shown in Figure 2. Foundational books as well as scientific articles, along with other books and websites, were the sources of information for a detailed review aimed to identify the different meanings of *Lean*.

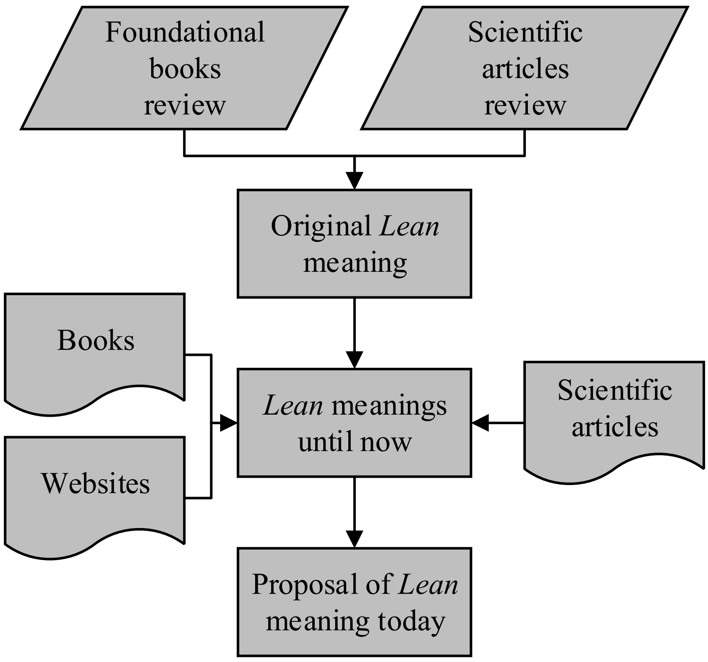

Figure 2: Structure of the research methodology

The analysis of *Lean* meanings encompassed the identification of the associated principles and concepts and led to a proposal of a single *Lean* meaning.

3 The meaning of *Lean* when the term was coined

The term *Lean*, within the context of production approach attributed to the TPS, was first published in 1988 in the article "*Triumph of the Lean Production System*" (Krafcik, 1988). John Krafcik was the first American engineer hired by the Toyota-General Motors joint venture, the designated New United Motor Manufacturing, Inc. (NUMMI). This was the initial implementation of Toyota's working methods on American soil. In this article, the term *Lean* is clearly associated with minimal inventory levels between various steps of the production process. To support this notion, the designation *Lean Production System* is contrasted with the *Buffered Production System*, the latter being the classic production type with substantial inventories between process steps to mitigate risks. The rationale behind high inventories is based on the idea that larger inventories (buffers) reduce the risk in case of any mishaps. The article also mentions the reduced space for repairing defective parts when the *Lean* approach was implemented (mostly in Toyota factories). Before the terms *Buffered* and *Lean* were used, respectively, the terms *Robust* and *Fragile* were also suggested to denote the same two concepts or production approach.

That article from John Krafcik suggests that the *Lean* approach carries both significant risks and substantial potential gains. The streamlined nature of the process, with minimal materials between stages, means that any issues - such as defects, equipment failures, or supplier disruptions - can lead to complete line stoppage. However, these risks are mitigated by skilled and knowledgeable workers, strong supplier relationships, a focus on getting things right the first time, and effective problem-solving strategies.

The term *Lean* (and the expression *Lean Production*) reappears shortly after in the famous book "*The Machine That Changed the World*" (Womack et al., 1990), which was actually authored by the same group of researchers to which John Krafcik belonged. This book may be the one that most significantly contributed to the widespread dissemination of the term worldwide. It is the result of a major MIT project that lasted five years and was dedicated to understanding the difference between Mass production and Lean production in the automotive industry. The authors clearly believed that this new method of production would change the world. Indeed, it did. With the *Lean* approach to production, performances close to those of mass production began to be achieved in environments with significant product diversity. In the book, the authors state that they assigned the name *Lean Production* to this new Japanese technique. They were actually referring to the approach developed by Toyota, which Toyota itself called the Toyota Production System (TPS). Several articles from the 1990s mention that *Lean Production* is the name given by James Womack's group at MIT to Toyota's way of working (Freyssenet, 1998; Linge, 1991; Rehder, 1992; Williams et al., 1992).

Another book by the same research group of great relevance to the understanding of the *Lean* philosophy or way of thinking was published later: Womack and Jones' book entitled "*Lean Thinking: Banish Waste and Create Wealth in Your Corporation*" (Womack & Jones, 1996). This book is famous for presenting the very known five principles of *Lean Thinking*. In this book the authors express the following: "... *an approach pioneered by the Toyota company after World War II. We labelled this new way 'lean production' because it does more and more with less and less"*. In fact, according to the authors themselves, the term *Lean* is attributed to Toyota's approach to production, because "*it uses less of everything compared to mass production - half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time*". What's more, it requires far less than half the stocks, produces far fewer defects and a greater and ever-growing variety of products. It is also pointed out that in order to achieve this, it is necessary to use teams of multi-skilled workers at all levels of the organization, and to use highly flexible and increasingly automated machines.

4 Principles and concepts associated with *Lean* according to the creators of the term

The principles and concepts presented in the publications mentioned above can be divided into two broad classes. These classes that shaped the TPS were first published in an English-language scientific journal in 1977 in the article "*Toyota Production System and*

Kanban System: Materialization of Just-in-Time and Respect for Human Systems" (Sugimori et al., 1977). In this article, the authors state that TPS is supported by two basic concepts: (i) "*Reducing cost by eliminating waste"*, and (ii) "*Treating workers as human beings and with consideration"*. The aim now is to assign to each of these basic concepts the concepts and principles referred to in the *Lean* publications mentioned above. With this list of principles and concepts, we basically have what constitutes *Lean*. Starting with the technical or physical side of production, the main principles and/or concepts mentioned by the MIT group led by James Womack are as follows:

- Specify Value - Concept of Value and the importance of identifying as best as possible what the value of products is from the customer's point of view; in the context of *Lean*, an activity adds value when it produces a transformation in the product that is recognized as valuable by the customer.
- Concept of waste - Any activity or task that does not add value to the product. Taiichi Ohno presents the seven types of these activities in the book he published in 1988 (Ohno, 1988): "*Waste of overproduction; Waste of time on hand (waiting); Waste in transportation; Waste of processing itself; Waste of stock on hand (inventory); Waste of movement; Waste of making defective products*".
- Identifying the value stream - The idea is to distinguish at every step of the process chain which steps add value and which steps do not.
- Concept of Pull Production Flow - This is a powerful concept that has a big visual impact on factories, as you only see small amounts of WIP, the transport systems are different, and there are lots of visual controls everywhere. This concept reduces throughput times, shortens delivery times and ensures that deadlines are met. Moreover, it provides a better use of resources, improving productivity. Associated with this concept are techniques such as *Kanban*, *one-piece-flow production*, *chaku-chaku*, *production and assembly cells*, *setup time reduction*, *heijunka*, *milk run*, etc.
- Concept of Visual Management - This concept is associated with transparency and making relevant information available in a simple way so that everyone is aware of what is going on, as well as information to help with decision-making. Examples of some techniques: Andon; 5S; kanban; etc.
- The concept of Autonomation (*Jidoka*) - This concept was developed in the 19th century by Sakichi Toyoda and was applied to looms to prevent faults without the need for a person. The idea is to apply sensors to the machines to detect faults and make them stop automatically or, if it is not possible to stop, to inform the operator of these faults.
- Other concepts and principles such as: Problem solving (5 whys); Strategic deployment (Hoshin Kanri); Standard Work; Total Maintenance; and Total Quality Management.

With regard to the human side of *Lean*, also referred as *respect for people*, the following examples are taken from the book "*The machine that changed the world*" (Womack et al., 1990):

- Teamwork - Throughout the book there are dozens of references to the importance of teams and teamwork. One example: "... *So in the end, it is the dynamic work team that emerges as the heart of the lean factory*"
- Giving operational teams management autonomy and decision-making responsibility - "...*It transfers the maximum number of tasks and responsibilities to those workers actually adding value to the car on the line*".
- Empowerment of workers - "... *each worker along the line can pull a cord just above the work station to stop the line if any problem is found*".
- Multi-skilled and challenging work - "*workers need to be taught a wide variety of skills .... Workers then need to acquire many additional skills: simple machine repair, quality checking, housekeeping, and materials-ordering. Then they need encouragement to think actively, indeed proactively, so they can devise solutions before problems become serious*."
- Giving workers specialist skills - "...*none of the specialists beyond the assembly worker was actually adding any value to the car. ...assembly workers could probably do most of the functions of the specialists and do them much better because of their direct acquaintance with conditions on the line*."
- Personal development - "...*companies must offer them a continuing variety of challenges. That way, they will feel they are honing their skills and are valued for the many kinds of expertise they have attained. Without these continual challenges, workers may feel they have reached a dead end at an early point in their career. The result: They hold back their know-how and commitment, and the main advantage of lean production disappears*."
- Transparent information for workers - "...*In a lean plant, ..., all information-daily production targets, cars produced so far that day, equipment breakdowns, personnel shortages, overtime requirements, and so forth-are displayed on Andon boards (lighted electronic displays) that are visible from every work station*".

In the other foundational book, "*Lean Thinking*" (Womack & Jones, 1996), the principle of the constant search for perfection (or continuous improvement) and the direction in which this constant search for perfection should be pointed is also expressed as part of this *Lean* approach to production. The book says that companies that adopt *Lean* also have perfection as an explicit goal: "*continuously decreasing costs, zero defects, zero inventories and an infinite variety of products".* This sentence clearly explains how the authors have defined their vision (or true north).

5 What is the meaning of *Lean* today (2024)

What has been presented so far shows what the understanding of *Lean* was in the late 1980s and early 1990s, ie., *Lean* (or *Lean Production*) was the name given to TPS, so it was the same as TPS. The challenge now is what should *Lean* mean today since different points of view vary across different scholars, consultants, and professionals. The question is whether: (a) *Lean* means the same as it was presented by James Womack's team in the

1980s, i.e. *Lean* is TPS; (b) *Lean* evolved into what the Toyota Way means today; (c) *Lean* evolved into new meaning(s),

6 *Lean* is the same as it was presented by James Womack’s team in the 1980s

The term *Lean* was assigned to designate the way Toyota was organizing and managing its production at the moment James Womack´s research team was observing the reality in Toyota plants. Based on that premise, the *Lean* meaning cannot be changed as Taylorism did not change or mass production concept did not change. Even if Toyota had changed its values, principles and concepts, the *Lean* meaning should be the same as when it was created. This position can be a possible position since many people may see it as having strong arguments.

7 *Lean* evolved into what Toyota Way means today

When comparing the TPS from the point of view of Sugimori et al. (1977) and the Toyota Way (Toyota, 2012), there are similarities between the “*Reducing cost by eliminating waste*” and *Continuous Improvement”*, and between “*Treating workers as human beings and with consideration*” and “*Respect for people”* (Figure 3). We think it would be worthwhile for the reader, certainly a person interested in the cause of *Lean* and operational excellence, to take a moment to realize the importance that these two concepts must have in order to aggregate Toyota's entire work philosophy. We repeat: all practices, routines, procedures, behaviour, culture, etc., are shaped by, or reflect, these two basic concepts. It can therefore be said that there is a more *technical perspective* and a more *human perspective*.

For some people Toyota Way is an evolution of TPS incorporating a stronger human perspective. Maybe that is the case but maybe not. The human side was already very present in the TPS as shown in Figure 3.

Apart from these two basic principles assigned to TPS by Sugimori et al. (1977) in the shape of philosophy or model, some specific techniques are also presented in the same article. Interestingly the TPS book from Taiichi Ohno (Ohno, 1988) a more technical perspective was given.

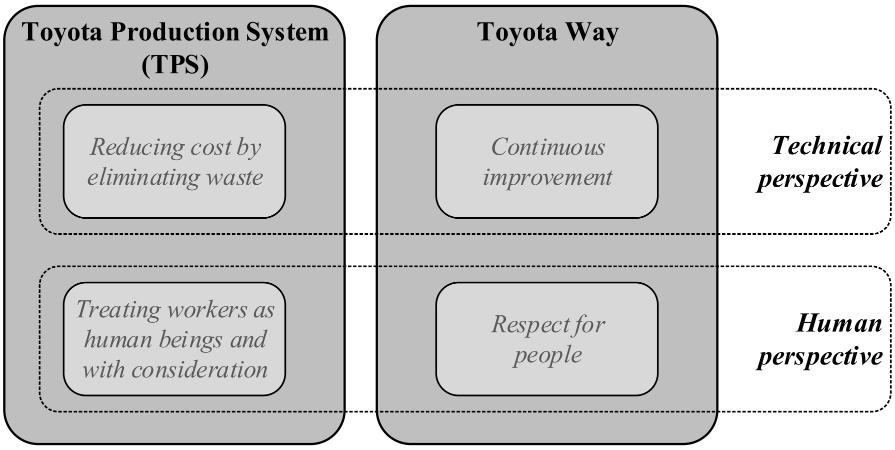

Figure 3: TPS (Sugimori et al., 1977) and Toyota Way basic concepts

In Ohno´s view, TPS is supported by two pillars (*Just-In-Time* and *Jidoka*) as can be shown in the left side of Figure 4. Toyota Way (Toyota, 2012), can be seen more as a philosophy that includes or gives the necessary background to the technicalities and concepts of TPS.

On the other hand, Jeffrey K. Liker, after working 20 years in Toyota factories, presented his own view of the Toyota Way (Liker, 2004) with its 14 principles. Some of those principles are more technical, such as "*Use pull systems to avoid overproduction*", "*Level out the workload*", or "*Jidoka*" while other are more conceptual such as "*Grow leaders who live the philosophy*" or "*Continual organizational learning through Kaizen*".

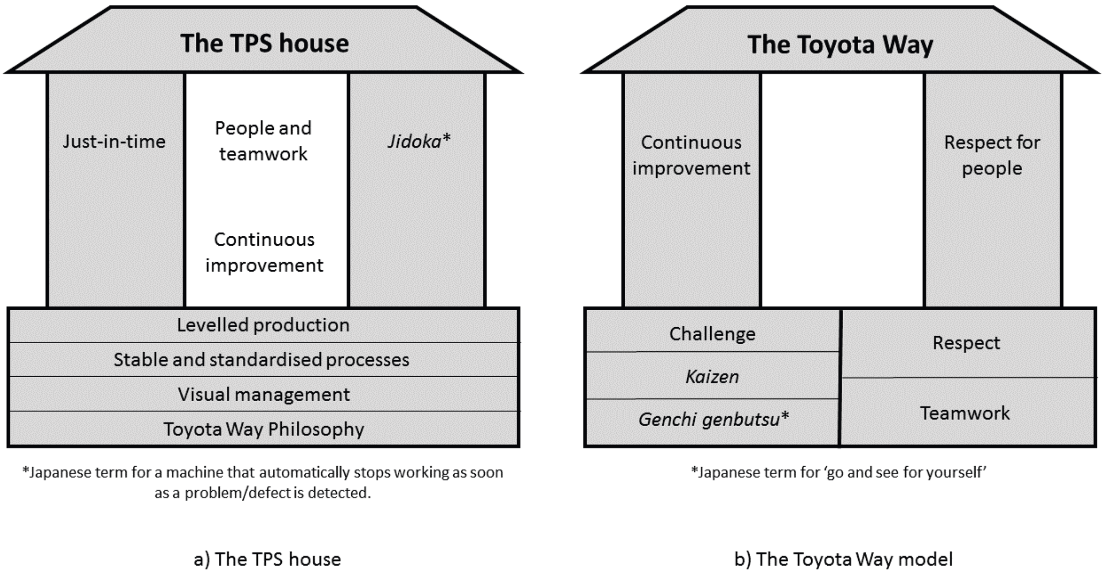

Figure 4: TPS house vs Toyota Way (Coetzee et al., 2016)

Interestingly, the original TPS house, as published by Narusawa & Shook (2009) (Figure 5), does not expressly include the human side referred to later and associated with TPS. On the other hand, Toyota Way clearly expresses the human side of the Toyota philosophy, that was not as well stressed in TPS, although it was there. Toyota Way, maybe seen as a reorganization of concept and principles that already existed in TPS. There is no discernible inconsistency or incompatibility between what was the TPS and what is the Toyota Way.

Figure 5: Original TPS house (Narusawa & Shook, 2009)

Assuming that the Toyota Way is the TPS with a new face, and assuming that *Lean* is the same as the TPS, as has already been proven, we can conclude that *Lean* is also the same as the Toyota Way. The concepts, principles and tools that were associated to the TPS/*Lean* by the original authors are perfectly aligned with the concepts and principles associated by Toyota Way, both in the publications on Toyota's official websites and in Jeffrey K. Liker's books.

8 *Lean* evolved into other meanings

According to Hines et al. (2004), Lean has evolved but it is not clear to what; the authors state that “Lean as a concept has evolved over time, and will continue to do so. As a result of this development, significant confusion about what is lean, and what is not has arisen”.

That confusion about the meaning of Lean, referred by Peter Hines, can be seen in many publications. Regarding the comparison between Lean and TPS, Lander & Liker (2007) argue that Lean is a misunderstanding of the fundamentals of TPS, regarding it as a set of specific tools implemented in a stereotyped way to achieve pre-specified results, while TPS is a philosophy or a set of general principles of organizing and managing an enterprise.

Another way of showing the referred confusion is through the various publications showing the negative aspects of Lean implementations. Some examples of such publications are:

- The article “Pushing back the frontiers: Management control and work intensification under JIT/TQM factory regimes” (Delbridge et al., 1992) argues that Lean Production methods can lead to work intensification and stress.
- Other authors, namely (Garrahan & Stewart, 1992; Williams et al., 1992) even suggested that Lean was implemented in Western industries as a means to exploit and dehumanize workers.
- The book “Just Another Car Factory? Lean Production and Its Discontents” (Rinehart et al., 1997) discusses also various negative impacts of Lean Production, including stress and repetitive strain injuries among workers.
- The article “Work design issues in lean production from a sociotechnical systems perspective: Neo-Taylorism or the next step in sociotechnical design?” (Niepce & Molleman, 1998), critiques Lean Production for its potential to revert to Neo-Taylorism, increasing worker stress and reducing job satisfaction.
- The article “Lean manufacturing comes to China: A case study of its impact on workplace health and safety” (Brown & O’Rourke, 2007). In this study the authors state that Lean manufacturing “…increases health and safety hazards” and that the intensification of work created by lean manufacturing “…leads to greater ergonomic and stress-related adverse health effects, as well as increased safety hazards”.

These and other publications allegedly present examples of applications of Lean concepts that have resulted in various types of problems for operators, such as stress, pressure to perform, ergonomic problems, and reduction of job satisfaction. The truth is that not every alleged Lean application is actually a Lean application. According to the findings of the article “The effects of Lean production on worker job stress” (Conti et al., 2006), Lean practices (LP) are not inherently stressful. According to the authors, the stress levels are significantly influenced by management decisions in the design and operation of Lean Production systems. If we look closely at all the concepts that have been presented by TPS/Lean, we come to the conclusion that in these negative examples some concepts have not been fulfilled. Examples of concepts or principles that have not been fulfilled include: “Respect for people” or “Treating the workers as human beings and with consideration” as well as the concepts of “Muri” (Ohno, 1988). Muri is considered an enemy of TPS and can be defined as overload, stress, repetitive work, or over demanding work. This means that since some of the Lean concepts were violated in these examples, we could argue that these cases could not have been called Lean applications.

After what has been said, our position is that Lean has not evolved into other meanings as has been mentioned in many publications. Let's just say that a lot of what has been labelled as applications and implementations of the Lean/TPS philosophy are not. They are something else.

9 *Lean* evolved to be applied in different contexts

The application of *Lean*/TPS principles and concepts has not been limited to the context of industrial production. These principles and concepts have been applied in other contexts and typically the terms adopted have been *Lean* followed by the identification of the context.

Examples include: *Lean Service*, *Lean Construction*, *Lean Healthcare*, *Lean Office*, and *Lean Education* (Table 1).

Table 1: Publications on Lean applied in different contexts.

	Year of the first publication in Scopus	Number of publications on Scopus	First Article on Scopus
Lean Service	1995	173	(Willetts, 1995)
Lean Construction	1996	2,099	(O'brien, 1996)
Lean Healthcare	2004	367	(C. Johnson et al., 2004)
Lean Office	2004	74	(Scheller II & Greenwood, 2004)
Lean Education	2006	73	(Robertson & Dufau, 2006)

Probably the first publication on Lean applied in other context than industrial production is in "Lean Service" (Willetts, 1995). Lean Service is proposed as being the application of Lean Manufacturing characteristics to the service industry and one example referred in the literature is the Taco Bell company (Bowen & Youngdahl, 1998). Lean Construction (O'brien, 1996) is a very popular subject in Scopus database with more than 2000 publications. Lean Healthcare (C. Johnson et al., 2004) is another important case of application of Lean philosophy in non-industrial sector. The first publications appearing in Scopus database referring Lean Office (M. Johnson & Priest, 2004; Scheller II & Greenwood, 2004) go back to the year 2004. It is called Lean Office (LO) the implementation of Lean Manufacturing philosophy in offices and administrative processes (Yokoyama et al., 2019). A last example is the application of Lean principles and concepts in education (Robertson & Dufau, 2006) both in the education institutions as well as in the process of teaching (Emiliani, 2015).

Yes, it is reasonable to agree that Lean/TPS principles and concepts can be applied with success in other activity sectors and not just in industry. Different tools and techniques are, and need to be, created to be more effective in different contexts in order to materialize the true north and the concepts and principles of Lean. Having that in mind we may agree that Lean has spread to many different sectors of activity and can continue as long as none of its concepts and principles are neglected.

10 Conclusion

The objective of this article was to answer the following questions: has the concepts and principles of *Lean* remained unchanged since its inception in the 1980s, closely mirroring Toyota's methodologies of that era? Should *Lean* today adhere strictly to the contemporary practices of Toyota? Or has it diverged and evolved independently over time?

Regarding the question, "*Is Lean the same as it was presented by James Womack's team in the 1980s?*", strong arguments can be used to say yes. It is crucial to recognize that *Lean* originated as a term coined by MIT researchers in the 1980s to describe the production methods employed by Toyota, i.e. the designated Toyota Production System (TPS). As Taylorism did not change or the concept of *Mass Production* did not change, *Lean* should also not change. Therefore, anything deviating from the principles and concepts embraced by Toyota during that era should not be classified as *Lean*.

The answer to the second question "*Has Lean evolved into what Toyota Way means today?"* is yes and no. It is *yes* because, as we argued earlier, Toyota Way is not different from what TPS was, and *no* because *Lean* did not evolve, it remained the same.

Our answer to the third question "*Has Lean evolved into other meanings*?" is no. Although many people claim that *Lean* evolved to other meanings, our position is that any meaning given to *Lean* that is not aligned to the concepts and principles originally defined, is not *Lean*. Any materialization of *Lean* that does not follow the original *Lean* concepts and principles cannot be considered as *Lean*.

Finally, we agree that *Lean* has spread with success into different contexts other than industry, without compromising its basic concepts. According to the context, the term *Lean* appears incorporating the context designations such as *Lean Office* or *Lean Construction*, among others. This is acceptable as long as there is no distortion between the materialization of the concepts and the concepts its selves.

Acknowledgments

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