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Applying the fundamentals of TPS to realize a resilient and responsive manufacturing system

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Abstract

Concepts like the Toyota Production System (TPS) and Quick Response Manufacturing (QRM) are often presented as alternative manufacturing methods or strategies suited for different manufacturing conditions. QRM is depicted as a Job-shop alternative (low volume-high mix) to TPS, and TPS is viewed as a method best suited for high volume-low mix environments. However, the realities of manufacturing organizations today are that they operate in a mass-customization environment with high total volumes to achieve economies of scale, and high variability due to the widening of choices available to customers. Which means that manufacturers must produce an infinite number of variants to serve individual customer needs, on a limited number of production lines, emphasising the need for both efficiency and responsiveness. In this paper we present preliminary findings from two Norwegian manufacturing companies who are applying the concepts of TPS to realize a resilient and responsive manufacturing system through a process of action learning. Instead of rigidly adopting the best practices developed by others, the companies are building flexible manufacturing systems through discovering their own paths towards improved quality, greater flexibility, and shorter lead-times - by finding and facing their challenges and engaging everyone in forming solutions, together.

Keywords: Lean Production, Toyota Production System, Responsive Manufacturing, Threshold Concepts, Organizational Learning

1. Introduction

The first examples of the practices we now associate with the Toyota Production System (TPS), originated in the job-shop environment of the Honsha machinery plant under the watchful eye of Taiichi Ohno and Kikuo Suzumura in 1950s Japan. Based on the concepts of "Jidoka" and "Just-in-time". These two fundamental concepts, along with Standardized work, Heijunka (leveling), Kaizen and Total Productive Maintenance (TPM) where instrumental in forming the production practices of Toyota at the time [1], and are still essential in forming the practices of Toyota to this day [2]. After the second oil crisis in 1979 western academics started to take an interest in what was happening in the automotive industry in Japan in general and particularly at Toyota. This was the starting point of a longitudinal study of the automotive industry that cumulated in the publication of "The Machine that Changed the World" [3]. In the book, Lean Production is presented as a full business system - from selling products to dealing with suppliers, to designing and manufacturing products, and of course, managing the enterprise. Indeed, if TPS and Lean Production's greatest potential is in *"realizing quicker, more flexible, higher quality response to customer entities"* [4], it is worth noting that Adler *et. al* [5] showed how Toyota moved beyond the efficiency/flexibility trade-off over 30 years ago. Despite this, the operations management research community has again recently tried to reduce the scope of lean production to a set of best practices and tools for efficient manufacturing in high-volume, low-mix environment [6].

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The ongoing research that forms the basis of this paper aims to test if the fundamentals of TPS can help establish a resilient and responsive manufacturing system in a low-volume, high-mix environment of "mass-customized" production environment. First, we investigated the fundamental principles and thinking that formed (and are still forming) the manufacturing tools and methods of Toyota, to see if these principles are specific or generic. Then, we framed these fundamentals as *Threshold Concepts,* which serves as a framework for testing the fundamentals of TPS through action learning research. This framework is currently being validated together with two different Norwegian manufacturing companies.

2. Literature Review

To better understand the fundamental thinking that lies behind the artifacts of the Toyota Production System, or what is now often referred to as Lean Production, Lean Manufacturing or just Lean, the tools and practices of the TPS should be regarded as responses, solutions or counter measures to site-specific problems [7]. TPS should not be described as a set of production practices, but as a set of concepts that forms the foundation of production practices. Indeed, Fujimoto concludes that Toyota's unique approach to manufacturing was created based on the evolutionary learning capabilities of Toyota, guided by the framework of TPS [8]. Ohno described Kanban and Standardized Work as frameworks that helped surface problems and promote Kaizen. [1]. Former alumni's of Ohno have dubbed TPS as "Thinking People System" [9] or "Toyota Process Development System" [10]. Furthermore, several recently published books written by former Toyota senior managers emphasize the learning and knowledge development that occurs through factual self-assessment (problem finding) and problem solving [11], and through radical improvement targets [12]. Moreover, they show how this is fundamental to the development of leadership skills at Toyota [13]. As such there is evidence that even Toyota employees do not regard the TPS framework as its production practices, but rather the framework from which production practices emerge. In fact, Ballé et al. go as far as to describe TPS as an education system that teaches leaders how to find and face problems [14]. However, no one has yet formally conceptualized and deliberately validated this approach to learning and development in collaboration with industry. The theory of threshold concepts provides a useful frame to explore the TPS as a framework for learning and development further.

3. Conceptual framework – TPS as threshold concepts

Threshold concepts are certain, subject-specific concepts that are considered central to the mastery of the subject. These threshold concepts have certain traits. They are [15]:

1. Transformative due to the conceptual and ontological shift that occurs when the concept is grasped
2. Irreversible as one will not likely forget it once a concept is understood
3. Expose the hidden interrelationship of a phenomena
4. Bounded
5. Involve troublesome knowledge

The threshold concepts of TPS can be described as "Value Engineering/Value Analysis (VE/VA)", "Just-in-time", "Jidoka", "Heijunka", "Standards", "Kaizen", "TPM", "5S" and "Problem solving". Each of these concepts address a typical troublesome problem, that is a problem that never seems to go away. The troublesome problems that the different threshold concepts addressed are "Customer satisfaction", "Lead-time", "Built-in-quality", "Load-leveling", "Mastery of know-how", "Development of know-how", "Team autonomy", "Individual autonomy" and "Support systems that work". The tools associated with the concepts should be regarded as scaffoldings that pinpoint hidden problems [16]. Thereby, these tools can surface learning and development opportunities in the form of problems - leading to a learning process called "Problem-based-learning" [17]. Figure 1 and Table 1 illustrate the threshold concepts and troublesome problems of TPS. Table 1 also provides examples of tools.

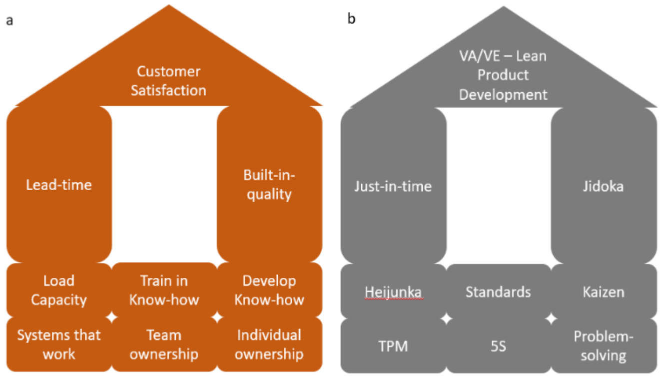

Figure 1 – TPS (adopted from [18] as troublesome problems (a) and threshold concepts (b)

Table 1. The relation between threshold concepts, troublesome problems and potential tools

Threshold Concepts	Troublesome Problems	Examples of tools
VA/VE	Customer Satisfaction	Lean Product Development tools
Pull/flow – Just-in-time	Leadtime	Kanban/One-piece-flow
Jidoka – don't make, don't pass defect	Build in quality	Andon. Poka-Yoke
Heijunka – load leveling	Load capacity	Yamazumi, SMED
Standardized Work	Mastery of know-how	Takt-time, Job breakdown sheet
Kaizen	Always increasing mastery	QC-circles, 8-step method
5S – ownership of workspace	Team Autonomy	5S tools
Problem solving	Individual Autonomy	5why, problem-solving sheet
TPM	Support systems that work	TPM tools

The combined approach of threshold concepts, troublesome problems and problem-based learning then forms the basis of developing the company-specific production practices needed to create a responsive manufacturing system through action learning. This system should be able to handle the mass-customization environment of our case studies. The assumption, which needs to be re-visited in the future, is that emergent practices based on individual and organizational learning can take longer to develop but are stickier and more resilient compared to best practices that are copied and implemented from elsewhere.

4. Research Method

Action research is similar to case study research but differs in one significant way. In case study research the researchers are observers, looking at the case from the outside. However, in action research the researcher becomes an active participant, and it is the change process itself that is the research subject [19]. Westbrook (1995), go on to suggest that action research is particularly relevant for technique development and for the building theory that is situation specific, emergent and incremental [20]. To gather useful data and develop actionable knowledge through questioning programmed knowledge, we engaged with two different companies in a process of action learning research. The action learning process followed Revans' theory of action in the science of praxeology in cyclical systems [21]. In the context of this research, Revans' system Alpha is the use of the TPS as threshold concepts to determine the environment of market and customers, current organizational performance and its origins, and management values. System Beta is the deep exploration of problems and resolutions through cycles of action and reflection on the framework that forms the basis of the process. Finally, System Gamma is the learning processes of those involved, researchers and practitioners alike.

The research is ongoing and in collaboration with two different companies in Norway. The interventions started in December 2020 and January 2021, respectively, and will continue through 2022. The companies are visited approximately once every two months, with some irregularities due to Covid lockdowns. Each visit is organized as an action learning intervention typically consisting of a gemba walk with senior leadership to discover and deliberately discuss problems, and to align on learning projects for senior management, based on the TPS framework; in other words, to question programmed knowledge to gain new insights. To measure the outcome of the interventions we study fundamental KPI's such as quality, and lead-time. In the next phase of the research process, we will study KPI's for productivity, such as sales per employee, return on assets, inventory turn-over and total sales.

5. Preliminary Findings

The action learning interventions where structured as gemba-walks [14], where researchers and practitioners study the value creation process in detail to gain deeper understanding of the overall implications these details might have on the company. For each gemba-walk, a threshold concept was either selected beforehand, or was selected during the intervention based on the direction the gemba-walk took. If the latter was the case, the gemba walk usually started with customer satisfaction, before moving down the TPS-house to lead-time, quality, load-leveling and so forth. The connection between each intervention and the threshold concepts are presented in table 2. Four interventions at each company, eight in total are presented here.

Case A Door Company is a medium sized manufacturing company with a Scandinavian market and an annual turn-over of approximately 40M Euros. Before commencing the action learning research initiative, the company had already established Lean practices, such as basic problem-solving, visual management boards and daily production meetings. However, the company still struggled with elevated levels of uncontrolled work in progress (WIP), poor delivery precision and, to a lesser extent, quality issues.

First intervention: A senior leadership gemba walk where the purpose of the gemba walk was to study load-levelling issues by applying the threshold concept of Heijunka. The gemba walk helped the team to better understand the importance of controlled WIP limits, as opposed to running each machine or resource at full capacity. The result was the establishment of visual WIP limits between stations with designated areas for storing WIP.

Second intervention: Another senior leadership gemba walk. The purpose of this gemba walk was to better understand the level of mastery of know-how, therefore the threshold concept of standardized work guided the gemba walk. However, during the study of a manual operation and after discussions with operators, problems with internal logistics, as well as quality and scrap problems with glass, due to how glass delivery was organized was discovered. This prompted two learning projects on internal logistics (just-in-time) and quality issues, or defects, related to broken glass (Jidoka) in the form of A3s with the intention to dig deeper into the problems, as there was no obvious and ready-made solution. A preliminary tool for the visualization of the material flow was developed, to enable operators to better see the problems and decide on improvement actions.

Third intervention: Following from the last intervention, it was decided to further study problems related to internal and external logistics. The gemba walk was also attended by a recognized lean expert who challenged the understanding of what how the visual management system should help seeing normal from ab-normal in terms of precision in logistics. This triggered a reflection on the internal logistics issues. Moreover, it set in motion a new A3, this time to find the necessary data for the visualization of the information flow, to improve the precision of internal logistics.

Fourth intervention: the starting point for this intervention was lead-time. However, after a gemba walk and a discussion it was decided to focus on a recently installed painting line that severely hampered overall productivity due to quality issues, which the company were struggling to bring up to speed. Up to this point, the company had left the problem-solving to the technical team and the team leader. However, the progress was not satisfactory, so the CEO decided to look at it as an opportunity to teach and practice structured problem solving to the plant leadership team. By applying the threshold concept of problem solving, the company surfaced that people were not autonomously working on solving problems, and that the leadership team did not support their efforts through TPM, which meant that there was a lack of mutual trust that needed to be addressed.

Preliminary results: The company has registered a decrease in customer complaints and stable overall quality level at 97% even though the introduction of a new paint line led to a temporary increase in quality issues internally. The company is currently developing good measurements for lead-time and productivity.

Case B Window Company is also a medium sized manufacturing company. It mainly focuses on the Norwegian market and specializes in manufacturing customized doors. The lean efforts of this company had been already acknowledged by Lean Forum Norway that named it 'The lean company of the year' in 2015. Over many years, the company had managed to reduce the lead time in manufacturing from 3 weeks to 3 days. The company continues to pursue lead-time reduction as a strategic priority.

First intervention: This intervention was named *Attack the Scrap!*. The company's middle-managers (production manager, quality manager, technical manager, etc.) were encouraged to go gemba and select one item of scrap product from the scrap trolley and investigate its origins. 'What is the reason for the scrap?' 'Where did it come from?' The underlying idea was to create learning opportunities by triggering curiosity and attention for quality, rather than simply reworking or re-ordering replacement parts, addressing the troublesome problem of built-in-quality.

Second intervention: *Bad-news first!* Though participants were very happy to present the results of the previous intervention, they were encouraged to 'never be satisfied', and rather think about the next problem to solve, increasing the know-how of individuals and teams. As such, the second intervention took the form of a workshop, to introduce managers and team-leaders to the concept of Kaizen through quality circles [22]. Though the organization had in fact implemented over 25,000 improvements in production during the previous years, strategic problem-solving, and a learning culture were still missing. Thus, team-leaders were assigned to form temporary, cross-functional teams to select and solve concrete problems in the factory.

Third intervention: *Operation broken glass*. This intervention stemmed from the idea of forming quality circles in the previous intervention. A team of leaders and operators set up an initiative to closely examine all instances of broken glass in assembly. Subsequently, countermeasures were implemented, and the derived learning was shared across teams. Over a three-month period, the team saw a 50% reduction in in-house breakages.

Fourth intervention: *Mistake of the day*. This intervention was established to celebrate failure as a means of further welcoming problems and finding success. Mistakes were escalated and presented to the local teams to foster a culture of continuous improvement and learning. Programmed knowledge was Toyota's "*cabbage patch*" concept, where bad or faulty parts are showcased to welcome countermeasures and prevent future occurrence.

Preliminary results: Again, the company experienced significant improvements in quality reducing both scrapped glass and customer complaints by 50%. It has also seen significant improvements in lead-time, especially in the factory, reducing the lead-time by 87,5% over the last year. However, similar to case a, there have been teething issues with new machinery and new processes which have hampered the company's ability to capitalize on the improvements.

Table 2. The relation between TPS threshold concepts and interventions

Action learning interventions	Troublesome Problem	Threshold Concept
Case A intervention 1	Load capacity	Heijunka
Case A intervention 2	Mastery of know-how / lead-time / quality	Standardized work / Just-in-time / Jidoka
Case A intervention 3	Lead-time / Precision of logistics	Just-in-time
Case A intervention 4	Individual autonomy / support systems that work	Problem solving / TPM
Case B intervention 1	Built-in-quality	Jidoka
Case B intervention 2	Increase know-how	Kaizen
Case B intervention 3	Increase know-how	Kaizen
Case B intervention 4	Individual autonomy	Problem solving

6. Discussion (cross-case analysis) and Conclusions

To deliver a product fast is one thing, to deliver the right product at the right price with the right quality is a whole different matter. As such, logistics and value chain management became strategic focus areas for both companies. The problems discovered through the action learning revealed that even though drastically reducing lead-time and increasing flexibility and responsiveness clearly was a strategic goal for both companies, there was also a need for facing problems related to customer satisfaction, cost, and quality. This is in line with a series of studies, highlighting cost, delivery, and quality as three main pillars of performance management (e.g., [23]) As the TPS framework addresses all of these troublesome problems, it served as a natural starting point of the learning journey towards a deeper understanding of the threshold concepts of TPS for both companies, which should lead to effective logistics and value chain management. Furthermore, we found that starting with customer satisfaction, or rather with customer dis-satisfaction was helpful in framing the challenge. This is in line with a the continuous strive of TPS to eenhance the creation of value for customers [24]. The challenge was framed by visualizing and analyzing the countermeasures to customer complaints, manufacturing quality issues and to supplier quality issues in the form of A3s or on visual boards. Finally, both companies have realized the need for visualizing the information flow to develop better precision in logistics. This supports a QRM strategy, that emphasizes the importance of streamlining not only the material flow, but also the information flow through the value chain - from the first request-for-quotation, through design and engineering, production, assembly, packing and shipping, invoicing etc., until the payment is finally received from the customer [25].

Both case companies have experienced improvements on some parameters and set-backs on others. However, unstructured interviews and reflective dialogue at both companies indicate that based on the observed trends, senior managers estimated significant performance improvements in the next 6 months as some structural improvements are fully implemented and more problems are surfaced and solved. To this end, the action learning research approach has proven itself useful in framing the business challenges, surfacing problems, and to guide problem-based learning, leading to a better grasp of the threshold concepts.

As all elements of the TPS are inter-connected, it was sometimes difficult to clearly distinguish which of the concepts that was applied. However, it helped to re-orient the intervention on the TPS concepts as it helped clarify which problem was being discussed and thus which of the different threshold concept was relevant for that problem.

Although this is an ongoing research project, the preliminary findings do point to some interesting insights. Framing the TPS as threshold concepts instead of manufacturing best practices enables people and companies to develop their own learning curve on the manufacturing fundamentals with the support of a Sensei [26]. Of course, this does not mean that one cannot buy and apply innovative technology or copy 'best practices' from other companies. It means that a company will have a better understanding of how the innovative technology or adopted best practices would function in their manufacturing environment, and the managers will engage in a more informed and systematic decision making. This study shows that threshold concepts aid in surfacing problems, and these problems are learning opportunities. When solving these problems, organizational learning happens, and an increasingly greater understanding of the threshold concepts is attained. As such, the TPS cannot be taught 'in a class-room'. Rather, companies will exploit the benefits of TPS through questioning its fundamental threshold concepts, continuously advancing production systems towards greater resilience and responsiveness by creating new, actionable knowledge.

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References

1. Shimokawa, K., Fujimoto, T.: Birth of Lean. The Lean Enterprise Institute Inc, Cambridge (2009)
2. News, T.: Akio Toyoda's View on Toyota Production System, https://toyotatimes.jp/en/insidetoyota/091.html, (2020)
3. Womack, J.P., Jones, D.T., Roos, D.: Machine That Changed The World. Harper Perennial, New York (1990)
4. Schonberger, R.J.: The disintegration of lean manufacturing and lean management. Bus. Horiz. 62, 359–371 (2019). https://doi.org/10.1016/j.bushor.2019.01.004
5. Adler, P.S., Goldoftas, B., Levine, D.I.: Flexibility Versus Efficiency? A Case Study of Modelt Changeovers in the Toyota Production System. Organ. Sci. 10, 43–68 (1999)
6. Hopp, W.J., Spearman, M.S.: The lenses of lean: Visioning the science and practice of efficiency. J. Oper. Manag. 1–17 (2020). https://doi.org/10.1002/joom.1115
7. Spear, S.J.: The Toyota production system: An example of managing complex social /technical systems. 5 rules for designing, operating, and improving activities, activity -connections, and flow -paths, (1999)
8. Fujimoto, T.: The evolution of a manufacturing system at Toyota. Oxford University Press, Oxford (1999)
9. Ballé, M., Beaufallet, G., Smalley, A., Sobek, D.K.: The Thinking Production System. Reflections. 7, (2006)
10. Hayashi, N.: Toyota Production System and the roots of Lean, https://vimeo.com/300443389, (2018)
11. Furuta, K.: Welcome Problems, Find Success. Taylor & Francis, Boca Raton, Fl (2022)
12. Nomura, S.: The Toyota Way of Dantotsu Radical Quality Improvements. Routledge, New York (2021)
13. Anderson, K., Yoshino, I.: Learning to Lead, Leading to Learn. Integrand Press (2020)
14. Ballé, M., Chartier, N., Coignet, P., Olivencia, S., Powell, D.J., Reke, E.: The Lean Sensei. Go, See, Challenge. The Lean Enterprise Institute Inc, Boston, MA (2019)
15. Cousin, G.: An introduction to threshold concepts. Planet. 17, 4–5 (2006). https://doi.org/10.11120/plan.2006.00170004
16. Bliss, J., Askew, M., Macrae, S.: Effective Teaching and Learning : Scaffolding Revisited. Oxford Rev. Educ. 22, 37–61 (1996)
17. Savin-Baden, M., Tombs, G.: Threshold Concepts and Problem-based Learning. In: Threshold Concepts in Problem-based Learning. pp. 1–17. Brill Sense (2018)
18. Ballé, M., Jones, D.T., Chaize, J., Fiume, O.: The Lean Strategy: using lean to create competitive advantage, unleash innovation, and deliver sustainable growth. McGraw Hill Professional, New York (2017)
19. Westbrook, R.: Action research: A new paradigm for research in production and operations management. Int. J. Oper. Prod. Manag. 15, 6–20 (1995). https://doi.org/10.1108/01443579510104466
20. Coghlan, D., Coughlan, P.: Notes toward a philosophy of action learning research. Action Learn. Res. Pract. 7, 193–203 (2010). https://doi.org/10.1080/14767333.2010.488330
21. Revans, R.: ABC of action learning. Gower, Surrey (2011)
22. Ishikawa, K.: Introduction to quality control. Springer, Tokyo (1990)
23. Chopra, S., Meindl, P., Kalra, D.V.: Supply chain management: Strategy, planning, and operation. Pearson Boston, MA (2013)
24. Womack, J.P., Jones, D.T.: Lean Thinking. Simon & Schuster UK LTD, London (2003)
25. Suri, R.: It's about time: The competitive advantage of quick response manufacturing. CRC Press, New York (2010)
26. Reke, E., Powell, D., Olivencia, S., Coignet, P., Chartier, N., Ballé, M.: Recapturing the Spirit of Lean: The Role of the Sensei in Developing Lean Leaders. In: Rossi, M. (Politecnico di M., Rossini, M. (Politecnico di M., and Terzi, S. (Politecnico di M. (eds.) Proceedings of the 6th European Lean Educator Conference, Lecture Notes in Network and Systems. pp. 117–125. Springer, Cham (2020)