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Heijunka 4.0 – Key Enabling Technologies for Production Levelling in the Process Industry

Håkon S. Kjellsen, Quentin J.L. Ramillon, Heidi C. Dreyer, and Daryl J. Powell

Department of Industrial Economics and Technology Management,
Norwegian University of Science and Technology, Trondheim, Norway
heidi.c.dreyer@ntnu.no

Abstract. This paper investigates how lean production levelling methods can be better applied in the process industry with support from key enabling technologies from Industry 4.0. To investigate such a topic, a literature study is conducted in three main areas, namely production planning in the process industry, Lean Production, and Industry 4.0. Based on the findings from the literature review, a conceptual framework is developed to illustrate the ability of Internet of Things, Big Data Analytics, and the further integration of IT systems to provide increased reliability for materials, processes, equipment, and forecasts that improves the utilization of Heijunka (production levelling) practices in the process industry.

Keywords: Process Industry, Lean Production, Industry 4.0.

1 Introduction

The current competitive business landscape is increasingly getting more volatile and uncertain. Therefore, companies must adhere to superior practices to be capable of meeting the new challenges of competing. Conventional lean production levelling methods have for several decades led to performance improvement in discrete manufacturing through offering greater predictability, flexibility, and stability for a wide range of companies [1]. However, the process industry has not yet embraced the real extent of benefits that lean manufacturing can offer [2]. This might be explained by the characteristics of the process industry that are inherently complex and inflexible, which makes a straightforward application of lean practices challenging [3]. However, such characteristics do not make it impossible to apply lean principles, as many process industries have shown promising results in improving operational performance using modified versions of certain lean practices [4]. Furthermore, the technology-oriented industry 4.0 concept is being branded as the next enabler of performance improvement in manufacturing [5]. Therefore, in this paper, we investigate how lean production levelling practices can be applied in the process industry, with particular focus on which Industry 4.0 technologies can support such an application.

Motivated by the research challenges and problems described above, we aim to use the following research question to guide our investigation: *How can key enabling*

technologies of Industry 4.0 support and enhance lean production levelling practices in the process industry?

2 Research Design

Given the nature of our research question, a preferable approach would have been to adopt case study research as our primary research method. However, due to the current restrictions on access to case companies and travels in response of the Covid-19 pandemic, we attempt to answer the research questions by developing a conceptual framework from literature review. Further research will explore the framework in empirical settings. As such, we explore existing and relevant theories, models, and findings through an extensive review of extant literature. The area of investigation is at the intersection of three major areas: production planning (in particular production levelling) in the process industry, lean production, and Industry 4.0.

We report the results of the literature review in Section 3. Section 3.1 focuses on the area of planning in the process industry while Section 3.2 focuses on lean production, as well as the intersection between lean production and production levelling in the process industry. Section 3.3 focuses on Industry 4.0, as well as how Industry 4.0 builds on traditional lean production principles and practices. In Section 4, by considering the theoretical overview surrounding the intersection of all three areas, we attempt to answer the proposed research question by offering a conceptual framework.

3 Literature Review

3.1 Production Planning and Control in the Process Industry

We start by giving a brief introduction to the notion of process industry, what characterizes it and how it differs from discrete manufacturing. This is followed by an investigation on what the main characteristics within process industries are, and how such attributes constitute potential barriers for the application of lean planning methods.

Discrete manufacturing normally consists of the manufacture of individual parts and components that machines and operators weld, bolt and assemble together to a complete product, with examples ranging from automobiles, cell phones, computers, power tools and hair dryers [3]. [3] also states that the process industry, on the other hand, is characterized by processes that involve mixing, extrusion, chemical reactions and annealing. Products that are used in such industries are often non-discrete materials which includes liquids, pulps, gases and powders and can often dry out, evaporate or expand if they are not put into a container [4]. Examples can range from different types of paints, processed foods and beverages, paper goods, fibres, glass, steel, aluminum and ceramics.

Planning and scheduling decisions are essential processes in company-wide supply chain and logistics management, and process industry operations are significantly

impacted by these decisions [6]. Planning in process industries creates plans within production, supply, distribution, sales, and inventory based on demand information while considering all known and relevant constraints [7]. For long- to medium-term planning, detailed routing information for sequencing is often required as “products are commonly defined by the succession of production steps which they undergo” [8]. Sales and demand information, availability of raw materials, simultaneous production of co-products and final products or optimal usage of expensive equipment have a significant impact on production planning and control [8].

The flow of materials in the process industry can differ from one batch to the next. [8] suggests that such industries must cope with variable recipes and specific sequences of transformation processes. Next, dedicated production technology and special storage equipment is often required for all materials that must be taken into account by planning and scheduling systems. Furthermore, according to [9], the production units and material flows tend to have more interrelationships, as both production flow and material complexity are higher. For these reasons, planning and scheduling in the process industry is complicated. Therefore, conventional planning methods such as MRP and lean levelling techniques, which are more associated with discrete industries, are hard to apply [2]. Such existing production planning and control concepts do not suit the needs of process industries in general [8]. Much of the extant literature supports the implementation of lean production and planning concepts in process industries, but due to its inherent characteristics it is challenging to apply these directly. This is especially true for the flexibility limiting characteristics such as long and sequence-dependent setup times and changeover cost which are in direct contrast to *Lean Production* [2].

3.2 Lean Production

This section introduces the lean philosophy, principles, and tools, and focuses on production levelling (Heijunka) practices in order to understand its effects, requirements, and its applicability in the process industry. Lean Production, largely based on the manufacturing principles and work processes developed by Toyota [10] and quickly spread to different industries [12]. [13] defines the basis of the Toyota Production System (TPS) as the absolute elimination of waste and suggests that this is the key to improving productivity and competitiveness. Lean Production is an enterprise-wide continuous improvement approach aimed at eliminating waste and creating value for the customer.

Lean production planning and control practices (e.g., production levelling) have enabled companies to improve their performance and reap high benefit. However, while Lean Production can be applied to various industries and types of organization [14], the adoption thus far has mainly taken place in discrete manufacturing, rather than in continuous or process industry sectors [3].

Production levelling is one of the essential Lean Production practices [15]. Also called Heijunka or production smoothing, it refers to the practice of levelling the volume of material that is being produced over time, such that the production level is as constant as possible from day to day. Particularly beneficial for the process industry

where stable production environments are preferable. According to [1], level production is scheduling the daily production for different product types in such a sequence that evens out peaks of the produced quantities. Production levelling can be conducted by gathering all orders over a specific period of time and scheduling the production at an even rate and in the mixed sequence, i.e., repetitive patterns [3]. According to this levelling pattern, every product type is manufactured within a periodic interval called the Every Part Every (EPE) interval. The general objective is to reduce the EPE interval to a cost-effective minimum [15]. The benefits of Heijunka include improved operational stability and reduced variability of resource utilization and material requirements, as well as reduced quality problems, breakdowns and defects. Despite these positive effects, however, levelling does not mean waste-free production. On the contrary, successful implementation of production levelling often requires a controlled inventory of finished products [15]. But, this often small inventory buffer enables the reduction of irregularity (mura) and overburden (muri), and reduces both the bullwhip effect and delivery lead time [16].

The Heijunka concept has been customized by several scholars to handle the different batch sizes and product mix that characterizes the process industry, for example EPE [1], Product Wheel [3], and Rhythm Wheel [17]. These new cyclical planning methods are based on a systemic and visual metaphor for a repeated planning methodology that aims to mitigate the variation in demand volume through optimized production sequences, enabling the creation of the best sequences of products and batches including into the calculation the setup and changeover time [3]. Moreover, capacity that is not fully utilized is often maintained for strategic reasons, such as reducing changeover times and carrying out continuous improvement practices [1]. However, Heijunka planning in the process industry increase planning complexity significantly causing the need for extensive planning and replanning capacity.

3.3 Industry 4.0 and Key Enabling Technologies

Industry 4.0 is characterized with several main technology clusters, including Cyber-Physical Systems (CPS) and Internet of Things (IoT) [18]. In a manufacturing environment, CPS and IoT facilitates the advancement of autonomous productive processes which become intelligent: “through communication and decision algorithms, the components can decide on their configuration and their path in the line production” [19]. Furthermore, according to [20], in Industry 4.0, the intelligence is distributed across the process steps and not centralized, which provide greater stability and operations flexibility, as well as reducing planning resources and ease replanning.

Industry 4.0 is promising for manufacturing companies, as new key enabling technologies will enable companies to gain a significant competitive advantage. As such, we can say that Lean Production and Industry 4.0 share the same objective, even though some consider them to be based on competing principles [21]. However, the empirical study of [22] suggests that Industry 4.0 technologies alone do not contribute to performance improvement and should rather be seen as enablers of Lean Production.

A literature study on how Industry 4.0 impacts Production Planning and Control (PPC) functions in general was conducted by [23], where the majority of research were mostly based on IoT technologies – concerning the integration of manufacturing execution systems and process control, interoperability, digitalization, real-time data collection, visibility, traceability and sharing of information. Hence, the most relevant industry 4.0 key enabling technology clusters for this investigation (using the classification of [24]) are IoT, Big Data Analytics and Integration of IT systems. This is also in line with the brief description of the Heijunka 4.0 concept provided in [25].

4 Conceptual Framework

To mitigate some of the inherent characteristics that inhibit lean production levelling (Heijunka) in the process industry, we suggest that it is possible to apply three specific, enabling technology clusters associated with Industry 4.0, selected from the classification provided in [24]. The framework is presented in Fig. 1, showing that the Industry 4.0 technologies IoT and Big Data Analytics can be applied to gather information regarding process industry characteristics that otherwise prevent the effective application of Heijunka methods, and integrates these into existing IT planning architectures such as ERP and APS software. The two-way arrows in the model illustrate that the elements are interconnected and communicates in real time.

Tools within the technology cluster IoT such as Radio Frequency Identification (RFID) and positioning sensors that measure times between specific product types and optical recognition sensors for determining product types can have significant impacts on Heijunka methods. High reliability of production processes is a prerequisite for such Heijunka methods, and IoT can enhance process management and control. Everything from variability in raw material quality to variations in internal processes and stock levels, such as dosing of raw material, temperature control, residence times, aging catalysts and system fouling will contribute to process variations. By using sensors and vision technology, to collect and connect data from various sources, and using Big Data Analytics for advanced calculations and simulations it is possible to predict process behavior, and increase production process reliability resulting in reduced changeover times, reduced production processing times, and increased available time for process improvement (e.g. predictive maintenance [25]).

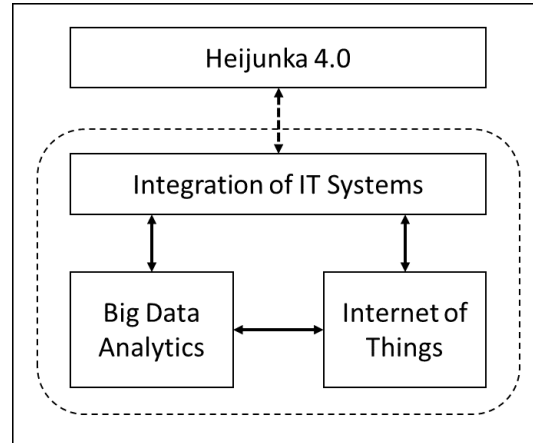


Fig. 1. Conceptual framework for Heijunka 4.0.

Furthermore, by utilizing IoT technologies, making material and equipment communicate with each other by using sensors such as Radio-frequency Identification (RFID), the equipment can quickly change to corresponding parameters, hence reducing the changeover times [26]. Furthermore, Big Data Analytics can use advanced simulation methods to optimize changeover and setups, by testing different methods [27]. As discussed in Section 3.2, shorter set up and changeover times will result in shorter cycle times for the Heijunka schedule, which could lead to more flexibility to meet demand variations. What has been discussed so far relates more to internal factors, such as material, process and equipment. Another important factor to make the Heijunka approach well suited is low variation in demand. Big Data Analytics that utilizes advanced algorithms and calculation methods enhances forecast quality, and the level planning can be stabilized by utilizing the combination of data history and a deeper understanding of customers' needs through in-depth analyses of the market.

This may also have a positive effect on the occurrence of waste (*muda*) arising from levelling practices. For example, [15] suggests that the successful implementation of production levelling often requires a controlled inventory of finished (or indeed semi-finished) products. Though this often small inventory buffer enables the reduction of irregularity (*mura*) and overburden (*muri*), and reduces both the bullwhip effect and delivery lead time [16]; by Integrating IT systems, the data information that is collected and calculated can thereafter be aggregated into the existing IT architectures such as ERP and APS for enhancing the Heijunka schedule. Parameters such as inventory replenishment levels, supply, production sequences and cycle times can be further optimized by utilizing information gathered and aggregated from IoT and Big Data Analytics regarding material, processes, equipment and demand, contributing to the elimination of traditional waste in the form of excessive inventories, but also reducing digital-waste in both its active- and passive forms (as described in [28]).

[29] also explores various sources of "buffer waste", where an organization's efforts to target *muri* and *mura* often generate unforeseen examples of *muda*. We suggest that the Heijunka 4.0 concept can be used to alleviate "*the muri, mura, and muda vicious cycle*".

5 Conclusion

We set out to investigate the potential support functionality of Industry 4.0 key enabling technologies for lean production levelling in the process industry. As such, we addressed the research question: *How can technologies associated with Industry 4.0 support lean production levelling practices in the process industry?*

It has been demonstrated in this study that Industry 4.0 technologies can both enable and improve the adoption of Heijunka in the process industry. The literature argues that Industry 4.0 supports lean principles, however, only a few studies study how individual industry 4.0 tools support specific lean practices. Thus, on the basis of these few studies, a conceptual framework detailing how the different tools of Industry 4.0 support the levelling of production in the process industry has been developed. This framework illustrates that the Industry 4.0 technology clusters *Internet of Things* and *Big Data Analytics* can provide predictability and visibility for factors such as process, material, equipment and demand. These types of data can be aggregated into existing IT systems, such ERP, MES, and APS that designs the level schedule, using the Industry 4.0 technology cluster *Integration of IT systems*.

In terms of limitations, although this investigation was carried out with the aim of having a strong practical involvement in bridging the gap between the application of lean production levelling practices in discrete manufacturing and in the process industry, further empirical studies are needed to assess and consolidate the conceptual framework. Indeed, multiple case studies applying the Heijunka 4.0 concept are required to evaluate the conceptual framework in greater detail.

References

- [1] D. Powell, E. Alfnes, and M. Semini, "The Application of Lean Production Control Methods within a Process-Type Industry: The Case of Hydro Automotive Structures," presented at the APMS 2009: International Conference on Advances in Production Management Systems, University of Bordeaux, Bordeaux, France, 19-23 September 2009, 2009.
- [2] P. Spenhoff, M. Semini, and D. Powell, "Investigating production planning and control challenges in the semi-process industry, the case of a metal parts producer," in *2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2016: IEEE, pp. 961-965.
- [3] P. L. King, *Lean for the Process Industries: Dealing with Complexity*. New York: Productivity Press, 2009.

- [4] F. A. Abdulmalek, J. Rajgopal, and K. L. Needy, "A classification scheme for the process industry to guide the implementation of lean," *Engineering Management Journal*, vol. 18, no. 2, pp. 15-25, 2006.
- [5] A. Ashrafian *et al.*, "Sketching the Landscape for Lean Digital Transformation," in *IFIP International Conference on Advances in Production Management Systems*, 2019: Springer, pp. 29-36.
- [6] D. E. Shobrys and D. C. White, "Planning, scheduling and control systems: why can they not work together," *Computers & Chemical Engineering*, vol. 24, no. 2-7, pp. 163-173, 2000.
- [7] J. Kallrath, "Planning and scheduling in the process industry," *OR spectrum*, vol. 24, no. 3, pp. 219-250, 2002.
- [8] Y. Crama, Y. Pochet, and Y. Wera, "A discussion of production planning approaches in the process industry," 2001.
- [9] J. C. Fransoo and W. G. Rutten, "A typology of production control situations in process industries," *International Journal of Operations & Production Management*, 1994.
- [10] M. Holweg, "The genealogy of lean production," *Journal of Operations Management*, doi: 10.1016/j.jom.2006.04.001 vol. 25, no. 2, pp. 420-437, 2007. [Online]. Available: <http://www.sciencedirect.com/science/article/pii/S0272696306000313>.
- [11] J. P. Womack, D. T. Jones, and D. Roos, *The Machine that Changed the World*. New York: Harper Perennial, 1990.
- [12] J. P. Womack and D. T. Jones, *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. New York: Simon and Schuster, 1996.
- [13] T. Ohno, *Toyota Production System: Beyond large-scale production* New York: Productivity Press, 1988.
- [14] T. H. Netland and D. J. Powell, Eds. *The Routledge Companion to Lean Management*. New York: Routledge, 2017.
- [15] J. K. Liker, *The Toyota Way: 14 Management Principles From the World's Greatest Manufacturer*. New York: McGraw-Hill, 2004.
- [16] B. J. Coleman and M. R. Vaghefi, "Heijunka (?): A key to the Toyota production system," *Production and inventory management journal*, vol. 35, no. 4, p. 31, 1994.
- [17] J. Packowski, *LEAN supply chain planning: the new supply chain management paradigm for process industries to master today's VUCA World*. CRC Press, 2013.
- [18] A. Sinha, E. Bernardes, R. Calderon, and T. Wuest, *Digital Supply Networks: Transform Your Supply Chain and Gain Competitive Advantage with Disruptive Technology and Reimagined Processes*. New York: McGraw Hill, 2020.
- [19] J. Lee, B. Bagheri, and H.-A. Kao, "A cyber-physical systems architecture for industry 4.0-based manufacturing systems," *Manufacturing letters*, vol. 3, pp. 18-23, 2015.

- [20] C. Klingenberg, "Industry 4. 0: what makes it a revolution?,(July), 1–10," ed, 2017.
- [21] F. Rosin, P. Forget, S. Lamouri, and R. Pellerin, "Impacts of Industry 4.0 technologies on Lean principles," *International Journal of Production Research*, vol. 58, no. 6, pp. 1644-1661, 2020.
- [22] S. Kamble, A. Gunasekaran, and N. C. Dhone, "Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies," *International Journal of Production Research*, vol. 58, no. 5, pp. 1319-1337, 2020.
- [23] A. F. Bueno, M. Godinho Filho, and A. G. Frank, "Smart production planning and control in the Industry 4.0 context: A systematic literature review," *Computers & Industrial Engineering*, p. 106774, 2020.
- [24] S.-V. Buer, "Investigating the Relationship between Lean Manufacturing and Industry 4.0," 2020.
- [25] A. Mayr *et al.*, "Lean 4.0-A conceptual conjunction of lean management and Industry 4.0," *Procedia Cirp*, vol. 72, pp. 622-628, 2018.
- [26] M. P. Ciano, P. Dallasega, G. Orzes, and T. Rossi, "One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study," *International journal of production research*, pp. 1-25, 2020.
- [27] M. Rübmann *et al.*, "Industry 4.0: The future of productivity and growth in manufacturing industries," *Boston Consulting Group*, vol. 9, no. 1, pp. 54-89, 2015.
- [28] D. Romero, P. Gaiardelli, D. Powell, T. Wuest, and M. Thürer, "Digital Lean Cyber-Physical Production Systems: the Emergence of Digital Lean Manufacturing and the Significance of Digital Waste," in *IFIP International Conference on Advances in Production Management Systems*, Heidelberg, 2018, Heidelberg: Springer, pp. 11-20.
- [29] D. Romero, P. Gaiardelli, M. Thürer, D. Powell, and T. Wuest, "Cyber-physical waste identification and elimination strategies in the digital lean manufacturing world," in *IFIP International Conference on Advances in Production Management Systems*, 2019: Springer, pp. 37-45.