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Technical Paper

Cost performance dynamics in lean production leveling

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ABSTRACT

Balancing of production systems is one of the main lean manufacturing principles as it reduces in-process storage and related forms of waste. A dynamic systems approach is proposed to investigate challenges of implementing production leveling and associated costs. A lean cell producing at takt time is modeled using system dynamics. The model captures various lean tools influencing production leveling and their implications. Comparative cost analysis between various leveling implementation policies for stochastic demand with multiple products is conducted. Results showed that determining the most feasible leveling policy is highly dictated by both the cost and limitations of capacity scalability. In addition, delivery sequence plans of different products/parts needed to achieve mix leveling and lot sizes affect the feasible production leveling policy while implementing lean principles. The developed model and insights gained from the results can help lean manufacturing practitioners to better decide when and how to implement production leveling as well as determine both production lots sizes and sequence. They also emphasize the importance of cost analysis as assisting decision support tool in the trade-off required between the benefits of different levels of lean policies and their associated cost.

1. Introduction

Global competition, uncertain demand environment and higher consumer expectations are among many drivers for companies to adopt lean manufacturing principles and tools. Lean principle can be characterized in short by "doing more with less". This lean philosophy focuses on the elimination of waste and excess from the tactical product flows and represents an improvement and sometimes an alternative model to that of capital-intensive mass production with its large batch sizes, dedicated assets and hidden wastes. Lean manufacturing offers a wide set of lean mechanisms and tools to achieve these goals. They include, but are not limited to, kanban pulling cards, SMED (single minute exchange of dies), TPM (total productive maintenance), kaizen (continuous improvement) and Poke-yoke (mistake proofing). Successful implementation of these tools and principles would result in manufacturing systems characterized by having high-velocity order-to-delivery and flexible processes which improve the overall business performance.

Efficient production leveling in terms of volume and mix to eliminate over-production, is among the fundamental targets of lean manufacturing where over-production means producing more, sooner or faster than is required by the next process [1]. Over-production causes additional handling, inspecting, counting and storing costs of those not yet needed products. In addition, with over-production, defects remain hidden in the inventory queues until the downstream process finally uses the parts and quality issues are discovered. Heijunka is the Japanese term for load or production leveling which is the lean manufacturing strategy employed to eliminate over-production. Leveled production attains capacity balance and synchronization of all production operations over time in a manner that precisely and flexibly matches customer demand for the system's products. Ideally, this means producing every product in every shift in quantities equal to demand after smoothing out high frequency random components. Manufacturing processes should be operated at the takt time to achieve level production. The takt time is the target production frequency, based on the rate of sales, to meet customer requirements. Takt time synchronizes the pace of production with the pace of sales. Producing at takt time is achieved through means such as rapid machine setups/changeover, just in time flow and scalable capacity strategies.

In the current dynamic business context, leanness assessment has undergone, and is still undergoing, a process of continuous and never-ending evolution [2]. The assessment of leanness impact was usually related to performance metrics that focus on system productivity, cycle and/or lead times and quality improvements. Although previous metrics have direct and indirect impact on the

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system cost efficiency, more attention needs to be paid to the assessment of lean tools implementation and their associated costs and dynamic effects.

This paper proposes a dynamic systems approach to investigate the challenges of implementing production leveling, as one of the main lean principles, and assessing its associated costs and dynamic effects. After reviewing the related work on lean dynamic analysis and lean cost assessments, a dynamic model for a lean cell is presented. The model captures various lean tools for production leveling and their cost implications. A numerical analysis for stochastic demand with multiple products is conducted and insights concerning production leveling implementation and feasible implementation policies are presented.

2. Literature review

Extensive review about lean manufacturing definitions, their development and related research work can be found in [3–6]. In this section, particular focus is placed on related body of work which explores lean implementation dynamic modeling and analysis combined with lean implementation costing approaches.

Various research works focused on the general implementation of lean systems from dynamic perspective. Amin and Karim [7] proposed a time-based mathematical model for evaluating the perceived value of lean strategies to manufacturing waste reduction and a step-by-step methodology for selecting appropriate lean strategies to improve the manufacturing performance within their resource constraints. Cheah et al. [8] developed a hierarchal approach to study challenges and dynamics of implementing lean policies using interpretive structural method. They showed that some lean policies have higher risk of failure than others depending in the various system dynamics. Kodua et al. [9] investigated the dynamics of process design in lean systems implementation using a dynamic value stream mapping approach. They focused on how to change organizations decisions in accordance to product realization requirements using a dynamic modeling approach. Black [10] presented a group of qualitative and quantitative dynamic rules to implement lean manufacturing. The approach focused on how to make current mass production industrial operation leaner. Black presented nine different design rules to achieve such transformation. Cochran et al. [11] applied axiomatic design principles to design lean manufacturing systems with focus on line segmentation. They showed that integrating axiomatic design rules with lean management improved the design and performance of manufacturing systems. Detty and Yingling [12] demonstrated the use of discrete event simulation as a tool to assist organizations with the decision to implement lean manufacturing by quantifying the operational benefits achieved from applying lean principles. Other simulation studies were also conducted to investigate the impact of Just in Time (JIT) and Pull lean principles on improving manufacturing system operational performance [13,14]. Lian and Van Landeghem [15] combined simulation and value stream mapping together with existing data bases of production to develop a tool for assessing lean implementation. They introduced a model generator to compare the current and the future system, before and after lean implementation, based on improving the value stream. The comparison allows mangers to make better decisions on when, where and how to implement lean manufacturing from a value perspective. Discrete event simulation to examine impact of implementing both Lean and Green policies on overall system performance was used in [16]. They presented a case study which showed that when Lean and Green techniques are well tailored to the system using simulation, optimal system performance can result.

Specific implementation of production leveling (Heijunka) includes the early work of [17] who suggested a simple algorithm for Heijunka scheduling that has been used in practice. De Smet and Gelders [18] noted that implementation of Heijunka was only possible in situations where few schedule disturbances existed meaning that demand was relatively stable and predictable. The trade-off between Heijunka and system's responsiveness was also demonstrated by Ref. [19]. Using an automotive case study, Ref. [20] demonstrated the need to balance between Heijunka and the Just In Sequence approach if the customer requirements are dynamic in nature. Deif [21] suggested a dynamic capacity scalability mechanism that incorporates the accumulated backlog and WIP levels to better manage the trade-off between Heijunka and responsiveness.

Lean implementation costing analysis was reported for example by Ref. [22] who developed a dynamic cost of quality decision support system for lean systems. The system was used to guide management to establish a lean manufacturing oriented quality policy and control the incorporated costs effectively. Lopez and Arbos [23] provided evidence of possible mistakes of current transaction-based cost accounting techniques in lean systems and proposed value stream costing (VSC) based on the known VSM as a better approach for lean manufacturing costing. Same result were given by Meade et al. [24] who proved using simulation that classical accounting costing can hide improvements gained by lean implementation. Modarress et al. [25] presented a case study describing a method used to implement kaizen costing and provided incremental cost reduction activities to support lean production implementation. Unlike traditional systems which consider the accumulation of costs or time but not both, [26] used cost-time profile (CTP) as a tool to estimate cost-time investments (CTI) in an organization and measure its lean level. By focusing on cost and time, the proposed tool evaluated the impact of implementing lean tools and techniques on the manufacturing system performance.

Analysis of the previous research work reveals that dynamic analysis of lean implementation focused more on policies and decisions that would enhance the system design and/or the operational performance with less attention paid to the cost implications associated with these policies and decisions. This was demonstrated in the case of production leveling (Heijunka) implementation where most of the work focused on the trade-off between system's leveling and responsiveness. Finally, few research articles on lean costing were concerned mainly with exploring the optimal costing approach for lean implementation assessment.

The work presented in this paper responds to the need for dynamic analysis of lean implementation costing, especially Heijunka policies. A system dynamics model that incorporates both Heijunka techniques as well as its associated costs is presented along with analysis of lean implementation costing.

3. Modeling production leveling in a lean cell

The system dynamics model for a lean manufacturing cell by Deif [21] is adopted and modified to incorporate production leveling mechanisms as well as their associated lean costs. The new model is shown in Fig. 1. The displayed system is composed of a demand component that captures the stochastic nature of the demand and translates it to takt time and pull rate. The production component is modeled as a lean cell with three production centers or stations. The production is controlled by a pull rate which is a function of takt time and is affected by the availability of materials via the JIT mechanism. The production leveling is maintained through a sequencing policy which impacts the change-over time and also through a scalable capacity component. The backlog of the developed cell is monitored as well as the accumulated WIP and both account for what is called the "Producer Cost". In addition, the cost of implementing each of the adopted lean tools (SMED,