CIRP Annals - Manufacturing Technology 63 (2014) 389–392

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Dynamic modelling of impact of lean policies on production levelling feasibility

Hoda ElMaraghy (1)[a,*], Ahmed M. Deif[b]

[a] Industrial and Manufacturing Systems Engineering Department, University of Windsor, ON, Canada
[b] Industrial and Service Engineering Department, Nile University, Cairo, Egypt

ARTICLE INFO

Keywords:
Systems
Dynamic
Lean implementation feasibility

ABSTRACT

A dynamic systems approach is proposed to investigate challenges of implementing production levelling and associated costs. A model of a lean cell is developed using system dynamics. The model captures various lean tools influencing production levelling. Comparative cost analysis between various levelling implementation policies for stochastic demand with multiple products is conducted. Results showed that determining the most feasible levelling policy is highly dictated by both capacity scalability cost and limitations. The developed model and revealed insights can help lean practitioners to better decide on when and how to implement production levelling as well as determine production lots sizes.

1. Introduction

Production levelling is the lean strategy employed to eliminate over-production. Levelled 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. Ideal levelling is achieved when manufacturing processes are operated at takt time to level production. However, such levelling comes with considerable cost that always challenges its successful implementation.

The assessment of leanness impact is usually related to metrics that focus on system productivity, cycle times and quality improvements. Although previous metrics have direct and indirect impact on the system cost efficiency, more attention needs to be paid to the assessment of lean tools implementation and their associated costs. This paper proposes a dynamic systems approach to investigate the challenges of implementing production levelling and its associated costs and dynamic effects.

2. Literature review

Dynamic analysis for implementation of production levelling (Heijunka) includes the early work of Monden [1] who suggested a simple algorithm for Heijunka scheduling that has been used in practice. It was noted by that implementation of Heijunka was only possible in situations where few schedule disturbances existed. [2] The trade-off between Heijunka and system's responsiveness was also demonstrated by Browning and Heath [3]. Using an automotive case study [4] demonstrated the need to balance between Heijunka and the just in sequence approach if the customer requirements are dynamic in nature. A dynamic capacity mechanism to better manage the trade-off between Heijunka and responsiveness was developed [5]. An inter-organizational network approach was suggested to solve this problem by Hermann et al. [6].

A lean implementation costing analysis was reported through a dynamic cost of quality decision support system for lean systems [7]. The system was used to guide management to establish a lean oriented quality policy and control incorporated costs effectively. Evidences of possible mistakes of current transaction-based cost accounting in lean systems was argued by Lopez and Arbos [8] and proposed value stream costing (VSC) based on the known VSM as a better approach. A study describing a method used to set kaizen costing and provided incremental cost reduction activities to support lean production implementation was presented by Modarress et al. [9]. Cost–time profile as a tool to estimate cost–time investments in an organization and measure its lean level was used [10]. This work was further integrated to evaluate the cost benefits of both lean and green tools implementation [11].

Previous research work reveals that analysis of production levelling focused more on policies and decisions that would enhance the system design and/or the operational performance with less attention paid to the associated costs. In addition, the few research articles on lean costing were concerned mainly with exploring the optimal costing approach for lean implementation. This paper attempts to address the need of more dynamic cost analysis of lean production levelling feasibility.

3. Modelling production levelling in a lean cell

The system dynamic model for a lean manufacturing cell in [5] is adopted and modified to incorporate production levelling 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. Production is modelled as a lean cell with three stations. Production is controlled by a pull rate which is function of takt time and is affected by availability of

* Corresponding author.

http://dx.doi.org/10.1016/j.cirp.2014.03.108
0007-8506/© 2014 CIRP.

Nomenclature

B(t)	backlog level at time t.
WIPi(t)	WIP level at t at station i.
IPR(t)	input production rate.
PR(t)	pull rate.
PSR(t)	production start rate at time t.
AD(t)	average demand at time t.
SD	standard deviation for demand
Avab.	system availability.
IO(t)	incoming orders at time t
OO(t)	outgoing orders at time t.
HFO(t)	hourly filled orders at time t.
AT	manufacturing available time
TT	takt time
%RC(t)	% of required capacity scaling
SDT	scalability delay time
SST	standard shift time
CO	change-over time.
JIT_{eff}	JIT implementation efficiency
$SMED_{eff}$	SMED implementation efficiency

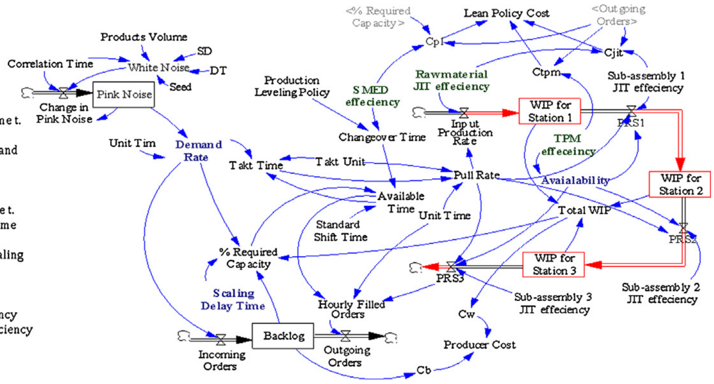

Fig. 1. Dynamic lean manufacturing cell and its nomenclature.

materials. The levelling is maintained through a sequencing policy which impacts the change-over time and also through a scalable capacity component. The model captures three lean tools: just in time (JIT), total productive maintenance and SMED. Costs of implementing lean tools as well as the costs of backlog and work in progress (WIP) are captured to constitute the production levelling cost.

3.1. Dynamics of lean manufacturing cell with production levelling

3.1.1. Stochastic market demand

The market demand is modelled as a stochastic parameter with dependent distribution or pink noise in Eq. (1):

$$\text{Change in pink noise} = \frac{\text{Pink noise } (t) - \text{White noise } (t)}{CT} \tag{1}$$

The demand rate (DR) is calculated in Eq. (2):

$$DR\ (t) = \frac{\text{Change in pink noise}}{\text{Unit time}} \tag{2}$$

3.1.2. Takt time and available time

Takt time is calculated by dividing available time by the customer daily demand rate as shown in Eq. (3):

$$TT = \frac{AT}{DR(t)} \tag{3}$$

The lean cell is augmented with dynamic capacity mechanism. Thus, the available time is calculated as function of the standard shift time (SST) plus hours based on scaled capacity if needed. The extra available time is introduced to maintain production-volume levelling. The mix policy is reflected in the model through Change Over time (CO). The changeover time is calculated based on the number of changeovers multiplied by the changeover standard time in Eq. (4). The CO is subtracted from the available time which is thus calculated (Eq. (5)):

$$CO = \text{Productionl leveling policy} \times CO_{\text{std}} \tag{4}$$

$$AT = SST(1 + \%RC) - CO \tag{5}$$

3.1.3. Dynamic capacity modelling

The use of dynamic capacity techniques is more common within today's new paradigms of changeable and reconfigurable systems [12,13]. A hybrid scaling policy is adopted from [5]. The required capacity based on the hybrid policy is shown in Eq. (6). Scaling delay time (SDT) is also captured.

$$\%RC(t) = \frac{(TWIP(t) + \text{Backlog}(t))/SDT}{DR} \tag{6}$$

3.1.4. Production control

To demonstrate the pull dynamics, production rate is set to be equal to a pull rate calculated based on takt time. In addition, the pull rate at each stage is also determined based on machine availability as well as readiness of materials and sub-assemblies required for each stage. To illustrate the role of lean tools in successful production levelling policies, the availability of machines can be increased by applying total productive maintenance (TPM) which is referred to as TPM efficiency. Furthermore, the readiness of materials and sub-assemblies can increase through applying JIT techniques which are referred to as JIT efficiency. The availability of each stage is stochastically modelled as random uniform distribution. The previous production dynamics are shown in Eqs. (7)–(9):

$$PR(t) = \left(\frac{TT}{\text{Unit time}}\right) \times \text{Takt unit} \tag{7}$$

$$IPR(t) = PR(t) \times JIT_{eff_i} \tag{8}$$

$$PRS_i(t) = PR(t) \times JIT_{eff_i} \times Avab_i \times TPM_{eff} \tag{9}$$

3.1.5. Backlog calculation

Backlog is calculated as the difference between input order rate and outgoing order rate. The outgoing order rate is a function in hourly filled orders based on both the production and the available time. Backlog calculations are in Eqs. (10)–(13):

$$\dot{B}(t) = OO(t) - IO(t) \tag{10}$$

$$\dot{IO}(t) = DR(t) \tag{11}$$

$$\dot{OO}(t) = HFO(t) \tag{12}$$

$$HFO(t) = PRS3(t) \times AT \tag{13}$$

3.2. Production levelling implementation cost

Studying the feasibility of applying production levelling policies requires calculation of two types of costs. The first is the cost associated with lean tools used to assist in successfully implementing production levelling – referred to as lean policy cost. The second is the costs incurred for managing the accumulated WIP and cost due to backlog referred to as producer cost. The cost structure used to calculate the production levelling cost is similar to the concept of activity-based cost (ABC) introduced by Cooper [14] It is considered by many researchers to be more suitable for lean costing than traditional transaction-based costing systems [7]. ABC estimates the product/service cost by assigning cost to the activities involved in their creation process. The activity cost pool is an aggregate of all the costs required to perform a lean production task.

3.2.1. Lean policy cost

The first cost is the cost associated with implementation of JIT activity. In order for JIT mechanisms to succeed and speed up the pull rate in the system, efforts should be made to reduce variability, maintain high level of synchronization with suppliers, dedicate resources for pull/kanban system and finally perform cross training. The cost of these activities is distributed over the