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Procedia CIRP 17 (2014) 577 – 581

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Variety Management in Manufacturing. Proceedings of the 47th CIRP Conference on Manufacturing Systems

"Dynamic Lean Assessment for Takt Time Implementation"

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Abstract

Increasing volatility, global competitiveness, and sales crisis all force the manufacturers to commit to the journey of world-class manufacturing performance via adopting "lean systems" to enable economic success in difficult times. Among the journey to lean, one of the hardest steps is measuring the progress of lean polices implementation especially in this highly dynamic market. This paper presents a dynamic model to evaluate the degree of leanness in manufacturing firms. The model is based on system dynamics approach and presents a "leanness score" for the manufacturing system. In addition, it examines the dynamics associated with the application of "One-piece flow" concept via "Takt time". Results show that working on adjusting the system's cycle times to follow takt time will improve the overall performance. Improvements are reflected in the overall service level, overall WIP efficiency, and overall equipment effectiveness. The developed model with its performance metrics will help the decision makers in adopting different lean policies and assist in optimal parameters settings of the system.

"Keywords: Lean assessment; takt time; one-piece flow; system dynamics"

1. Introduction

Due to the market instability and the frequent introduction of innovations in processes and technologies, manufacturing system' managers are facing the need to continuously adapt the system architecture and the operational parameters to meet profitable operating conditions and remain competitive in the global market [1]. Numerous companies have adopted lean production in order to survive in today's competitive markets.

One of the main tools of lean manufacturing is takt time. According to the Boeing website regarding Lean initiatives, "Lean does not mean doing things faster; it means doing things at the right pace. Essentially, the customer s rate of demand establishes the pace, or takt time". Rather than maximizing the production rate and factory utilization to their fullest potential, production rates are determined by customer demand, ensuring that customer needs can be satisfied in a timely and predictable fashion.

The main advantages of system dynamics include a means to understand the system by identifying relationships among factors, the use of a structured model that allows decision makers to simulate current functioning of the system and to explore opportunities for improvement, and assistance for decision makers in predicting system sustainability performance metrics for various system alternatives [2].

This paper measures the degree of leanness of a production system and evaluates the effect of producing according to takt time on leanness score. A system dynamics approach is adopted to model a multi-product, multi-stage production system for that purpose.

2. Literature review

Simulation of lean system performance comprises a significant share of lean dynamics literature. An analysis of the performance of just-in-time production systems was

doi:10.1016/j.procir.2014.01.128

conducted with exploring the effects of operating policies on system performance measures in [3]. A further work was done by examining the performance of multi-item, multi-line, multi-stage JIT and the impact of some factor settings on some performance measures via simulation with SLAM II in [4]. The use of discrete event simulation was demonstrated as a tool to assist organizations with the decision to implement lean manufacturing by quantifying the benefits achieved from applying lean principles in [5]. An assessment of current and future value stream map (VSM) via simulation with Arena was developed by [6].

The need for lean assessment is apparent as a consequence of the divergence among authors in identifying lean production which lead to confusion in the theoretical level and problematic issues in the practical level. So, each organization want to implement lean production should select tools, concepts, techniques that satisfy its own needs [7]. Data Envelopment Analysis (DEA) technique was used by [8] to measure the overall leanness of a value stream mapping (VSM) considering cost, time and output value. To assess the enhancements achieved through the application of lean tools and techniques, a cost-time profile (CTP) tool was developed for monitoring the accumulation of cost in the manufacturing of a product through time in [9]. An adaptive lean assessment approach was used as a guide to the lean implementation by recognizing web-based program for each user to evaluate the current status of organization and the opportunities for improvement in [10]. Fuzzy membership functions were developed as an approach to evaluate the lean performance of manufacturing systems by [11]. With the growth of green technologies and its connection with lean technologies, an assessment methodology for simulating, optimizing, and valuating a manufacturing system's performance indicators while using a tailored combination of lean and green strategies was developed by [12].

An approach to dynamically model and analyze manufacturing systems, and especially their different planning and control policies, is system dynamics (SD) introduced by [13]. SD has distinctive performance when considering strategic issues in manufacturing companies [14]. Application of SD in manufacturing systems to date focused mainly on pure inventory dynamics and supply chain where the objective was to study how the system can be designed and analyzed to respond to unanticipated demand with maximum stability and minimum cost [15-16]. System dynamics simulation model was also used by [17] to explore and understand how the physical flow, information flows and company policies interact to generate the dynamics of the remanufacturing process and to investigate and evaluate effective control strategies aimed at improving the performance of the system.

A dynamic model for capacity scaling was developed in reconfigurable manufacturing systems (RMS) and was analyzed based on control-theoretic approaches to indicate the best design for the scaling controller [18]. A proposed SD single stage model for capacity scalability in make-to-order manufacturing was presented [19]. It used various performance measures to examine the best scaling policy under different demand scenarios. Also, SD was used to compare between traditional supply chain and leagile supply chain [20]. The impact of dynamic disturbances in manufacturing process on the production planning and control (PPC) in job-shop manufacturing was investigated by [21]. Comparing between two models for a supply chain under two conditions of supply disruptions, without backup supplier, and with a contingent supplier was done by SD [22]. Building SD model to investigate the dynamics associated with single lean manufacturing cell was developed in [23]. It was showed that although lean cell is expected to be responsive to external demand with minimum waste, however, this was not the case under the considered uncertain conditions.

From the previous review, most of the work focused on the rules and recommendations to apply lean manufacturing or the different approaches to improve many aspects of lean manufacturing tools. Although the literature offered tools, models, and techniques to assess the leanness degree of manufacturing systems, few work studied the lean systems from a dynamic perspective. Such dynamic analysis in today's uncertain environment is fundamentally critical to understand and thus better manage lean manufacturing systems and keep competitive advantage for firms. This paper adapts the system dynamics model developed by [24] to assess the effect of applying "One-Piece flow" concept via takt time on the leanness score.

3. Dynamic lean manufacturing model

The system dynamics model developed by [24] is modified and the new model is shown in Fig. 1. The analysis of the manufacturing system will compare two scenarios of production set by the production planners. The first is to produce at the original cycle time and the second is to produce at the takt time.

The manufacturing system is composed of four components which are production system, quality system, backlog system and leanness score evaluation system. The production system involves four stages, three of them are concerned with manufacturing and the fourth is the finishing stage. The four stages are controlled by stochastic cycle time for each stage. In addition, the quality system is based on sampling techniques at the end of the manufacturing process and is controlled by inspection time. Furthermore, the backlog system is an indication of the delay between the placement and delivery of orders. Finally, the leanness score system is composed of three metrics which are Overall Equipment Effectiveness (OEE), Overall Work-in-process Efficiency (OWE), and Overall service level (OSL).

OEE measurement is commonly used as a key performance indicator (KPI) in conjunction with lean manufacturing efforts to provide an indicator of success. In addition, OSL is the level at which the customer orders is filled on time. Furthermore, OWE is an indicator of the accumulation of WIP over time reflecting internal efficiency as well as stability.

Model equations are explained in table 1. The equations will reflect the uncertainties and dynamics associated with the manufacturing system.

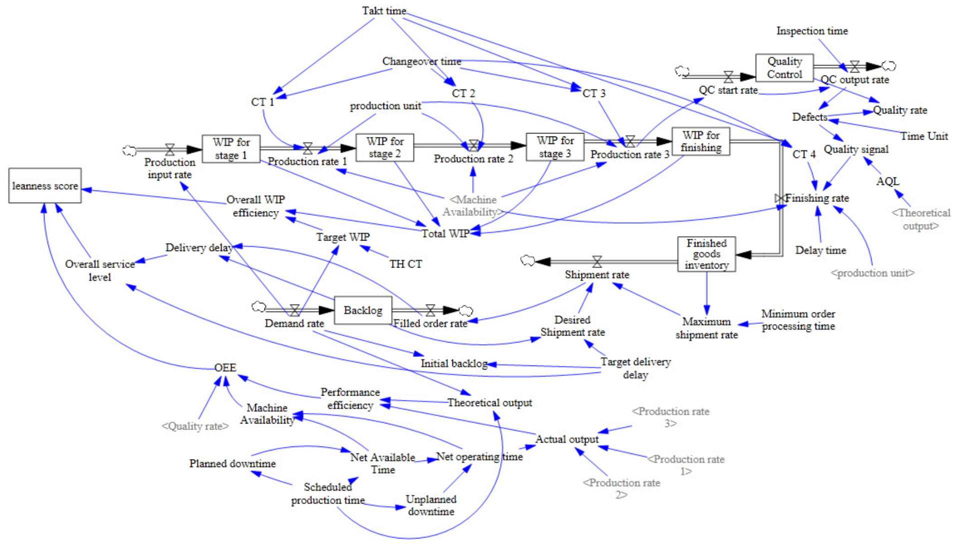

Fig. 1: Model with takt time =

Table 1: Model Equations =

No. =	Equation =
1 =	WIPi = INTEG (PRi-1 – PRi, 0) = =
2 =	PIR (t) = DR (t) =
3 =	PRi = (1/CTi) * MA/100 =
4 =	CTi= RANDOM NORMAL (Min, Max, Mean, SD, Seed)-= COT =
5 =	DR= RANDOM NORMAL (Min, Max, Mean, SD, Seed) =
6 =	COT= RANDOM NORMAL (Min, Max, Mean, SD, Seed) =
7 =	B (t) = INTEG (DR (t) – FOR (t), B0) =
8 =	FOR (t) = SR (t) =
9 =	SR (t) = MIN (DSR (t), MSR (t)) =
10 =	DSR (t) = B (t)/TDD =
11 =	B0 (t) = TDD*DR (t) =
12 =	MSR (t) = FGI (t)/MOPT =
13 =	FGI (t) = INTEG (FR (t)-SR (t), B0) =
14 =	QC (t) = INTEG (QCSR (t) –QCOR (t), 0) =
15 =	QCOR (t) = DELAY FIXED (QCSR (t), IT, QCSR (t)) =
16 =	QCSR (t) = PR3 (t)*(sample size) =
17 =	QS= IF THEN ELSE (DF<=AQL, 1, 0) =
18 =	FR (t) = IF THEN ELSE (QS>=1, 1/CT4 (t), 1/ (CT4 (t) = +DT))*MA/100 =
19	DF (t) = RANDOM NORMAL (Min number of defects = *QCOR (t), Max number of defects *QCOR (t), Mean number = of defects *QCOR (t), SD number of defects *QCOR (t), = Seed) =
20 =	LS= ((OEE+ OWE+ OSL)/3)*100 =
21 =	OEE % = MA*PE*QR =
22 =	MA %= (NOT/NAT)*100 =
23 =	NOT = NAT-UPDT (t) =
24 =	NAT = SPT-PDT =
25 =	UPDT= RANDOM NORMAL (Min, Max, Mean, SD, = Seed)*SPT =
26 =	PE % = IF THEN ELSE ((AOUT>=TOUT), = (TOUT/AOUT)*100,(AOUT/TOUT)*100) =
27 =	AOUT= NOT*MIN ((MIN (PR3, PR2)), PR1) =
28 =	TOUT= SPT*DR =
29 =	QR % = (QC-DF)/QC*100 =
30 =	OWE= IF THEN ELSE ((DWIP<=TWIP), = ((DWIP/TWIP)), ((TWIP/DWIP))) =
31 =	TWIP $\int_0^t$(WIPi(t) /4 =
32 =	DWIP= DR*THCT =
33 =	OSL= ((TDD)/DD)*100 =
34 =	DD= B (t)/FOR =
35 =	CTi = TT – COT =

4. Investigating the dynamics of "takt time" policy

In =this =section, =the =analysis =of =the =multi-stage, =multi-= product =manufacturing =system =is =provided. =This =analysis = examines the dynamics associated with pacing the processes' = cycle time with takt time and its impact on the overall = leanness score. The model is simulated for 160 hours. =

4.1. The impact of "takt time" on the overall WIP efficiency

One-piece =flow =means =that =parts =are =moved =through = operations from step to step ideally with no work-in-process = (WIP) =in =between. =Fig. =2 =compares =the =WIP =efficiency = performance for the two scenarios of producing at the selected = cycle time and at the takt time. =

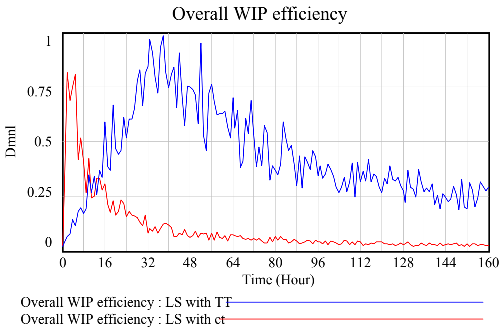

Fig. 2: WIP efficiency with cycle time and takt time

Analysis of the figure shows that producing at takt time supersedes the production with the original cycle times from a WIP performance perspective. The decline in the WIP efficiency in both scenarios is mainly due to the accumulation of WIP over time. This highlights the importance of implementing other lean tools that can manage the accumulated WIP such as JIT techniques and not depending only on producing at takt time strategy. Takt time strategy is will show its best efficiency in very stable and balanced systems, however, all manufacturing systems suffer from multiple inherent inefficiencies and nonlinearities.

4.2. The impact of "takt time" on the overall equipment effectiveness

The objective of the OEE metric in the lean context is to identify sources of losses that affect the ability to achieve business goals, which then can uncover multiple opportunities of improvement strategies. Fig. 3 compares the OEE for the investigated production scenarios.

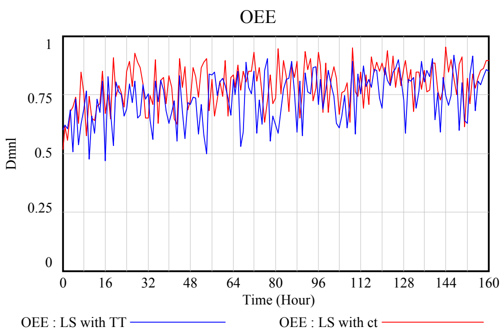

Fig. 3: OEE with cycle time and takt time

It is shown from the figure that producing at takt or at cycle time would have close impact on OEE. The reason behind that is the dependence of OEE mainly on quality and reliability of the system and both are not sensitive to the production time policy.

4.3. The impact of "takt time" on the overall service level

The overall service level (OSL) measures the responsiveness of a system to customer orders. Fig. 4 compares the impact of producing at takt time and normal cycle time on overall service level.

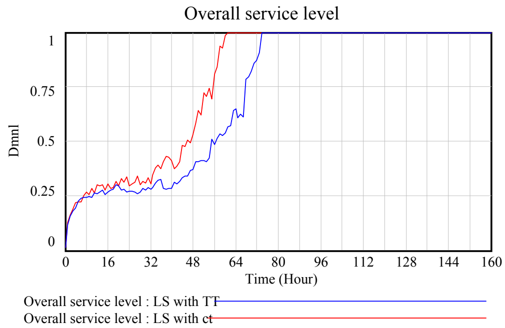

Fig. 4: OSL with cycle time and takt time

The analysis of Fig. 4 indicates that producing at normal cycle times set by the production planners will lead to a better OSL than producing at takt time for some period of time (as both reach 100% later). This can be explained by realizing that eliminating WIP using takt time will come on the expense of system's responsiveness for some time till the system reaches its stability at this pace. This is what proponents of allowing WIP accumulation refers to as the role of WIP to respond quickly to demand at the early stage of production. However, a trade-off should be considered at this point to balance between this quick response at this short period versus the other negative impacts of high WIP accumulation levels.

4.4. The impact of "takt time" on the leanness score

Fig. 5 compares the overall impact of producing at "takt time" versus producing at different cycle times on the new developed total leanness score metric.

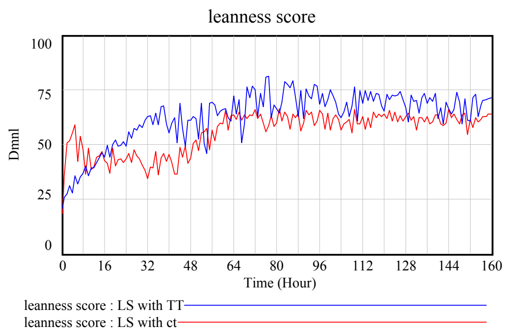

Fig. 5: LS with cycle time and takt time

The total leanness score shows a better performance with the implementation of producing at takt time policy. The new developed metric supports the importance of synchronizing production systems at takt time to maintain better leanness levels.

5. Conclusion and recommendations

This paper presented a system dynamics model to measure the degree of leanness in any organization under stochastic conditions. The model analyzed the dynamics associated with manufacturing systems producing at takt time versus producing at different cycle times using a new developed leanness score metric and its different components. The main conclusions and recommendations from the previous analysis can be listed as follows:

- Implementation of takt time will improve the overall WIP efficiency to a good value. It helps decreasing the WIP between stages and the finished good inventory. However, managing accumulated WIP in lean systems should be through integrating takt time production policies with other JIT techniques.
- Takt time policy has no significant impact on the overall equipment effectiveness (OEE) as it is primarily depends on quality and system reliability.
- Although it was expected that the takt time will increase responsiveness level, the results shows that it is not the case for the early production period when compared to the different cycle time production scenario. So, tradeoff analysis is needed to balance between the positive and negative impact of takt time implementation on early responsiveness level of the system.
- One of the main success factors of the application of "one piece flow" concept is the full stability of the system which is not the case in the practical experience. Thus with manufacturing systems nowadays suffering from various dynamics, variability and instabilities; similar dynamic analysis of lean systems comes with crucial importance.

The developed model with its new metric supports the importance of adopting takt time production policies. It also gives lean practitioners a better insight about the dynamics associated with the implementation of such policy which can help them in optimal settings of the system parameters as well as some of the required trade-off decisions.

Future work is required to investigate the impact of different lean policies over the leanness score. For example, the impacts of implementing JIT, TPM, SMED, Jidoka, etc. under stochastic conditions on the different performance measures. In addition, the effect of the quality level may be investigated. Moreover, sensitivity analysis for the different parameters involved in the model will help in better understanding the role of these parameters in lean system performance.

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