A convex relationship between batch size production, WIP and manufacturing management philosophies: A study using the Factory Physics methodology approach

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Abstract: The study presents a quantity model that use a Factory Physics methodology approach (HOPP; SPEARMAN, 2001). It aims study the impacts of five continual improvement projects (variability in the process and on arrival, time to failure and repair, and set up time), also it simulates the model to three production batch sizes in the middle level of work in process (WIP) and Utilization. In addition, the application in the use in a production environment with a single machine that processes multiple products. The results of work is possible get insights and subsidies with the model that support a number of modern tools and manufacturing management philosophies, Six Sigma; SMED (Single Minute Exchange of Die), Toyota Production System / Lean Manufacturing and Quick Response Manufacturing (QRM). Besides, the model also serves to assist in the choice of different possibilities for continual improvement programs on the factory floor.

Keywords: Factory Physics; production batch size; continual improvement; WIP; Utilization.

1. Introduction

Nowadays, paradigms moderns and manufacturing management philosophies like Six Sigma, Toyota Production System / Lean Manufacturing, and the Restrictions Theory, They have seeking to achieve long-term competitive advantages through continual and incremental improvements on the shop floor (GODINHO; UZSOY, 2009). Consequently, there has been various tools focused on improving the shop floor, for instance, the reduction of size batch, Total Production Maintenance (TPM), and set up reduction techniques, among many others. However, although of the extensive literature that discusses and defends these types of improvement programs, still miss the clear understanding of the conditions which it is expected to work well, and how these programs help to obtain competitive advantages related to specific variable. We observed that in the literature there are few models that help in understanding of how improvement efforts, focused on different aspects of manufacturing, impact key performance variables manufacture, such as work in Process (WIP) and Utilization.

The study seek to bridge this gap by proposing of a quantity model, which use the approach of Factory Physics (HOPP; SPEARMAN, 2001). It aims study the impact of the five continual improvement project and change the production batch size in average levels of work in process (WIP), and Utilization in a production environment with a single machine that processes multiple products.

Currently, the simulation has been used by some authors to quantify and justify the implementation of systems in manufacturing systems (CHINET; GODINHO, 2014), as shown by Riezebos (2006), Baysan, Kabadurmus and Durmusoglu (2007) and Harrod and Kanet (2013).

The five continual improvement project analyzed are relative to the following parameters. (*i)* variability in the rate of arrival in the orders in the system; *(ii)* process variability (composed by the natural variability of the process, repair time variability, and variability of the set up time); *(iii)* mean time to equipment failure; *(vi)* mean time to repair equipment; *(v)* mean time to set up.

The scenario considered in this study was related to a simulation of the implementation of projects for a major improvement (50% improvement) in the analyzed parameters. This scenario was conducted in order to study two performance variables on the shop floor: Stock in Process (WIP) and Utilization Rate. Moreover, in simulation environments, values of the production batch size were varied in order to verify the results obtained are sensitive to changes in production lots.

The organization of study as follows: in Section 2 a brief review of the literature about the main topics, covered (Continual Improvement and Factory Physics) presented; Section 3 shows the model developed and realized scenarios; in Section 4, the experiment results; and in Section 5, the conclusion.

2. Literature Review

2.1. Continual improvement – CI

According to Bhuiyan e Baghel (2005) over the decades many CI methodologies, like lean manufacturing and six sigma, there were developed. They said, CI programs have evolved from traditional practices focused on manufacturing in order to reduce waste and improve quality for systematic methodologies focused on the organization as a whole."

The five CI project discussed on this study involve improvements in two parameters: a) variability (HOPP; Spearman 2001) - variability in this study is measured in terms of coefficient of variation, in other words, in terms of ratio between standard deviation and average; and, b) time and average rates.

As define Hopp and Spearman (2001), variability as the "non-uniformity attribute of a set of items." According to these authors, high variability always degrades performance (with respect to inventories, capacity and time) of a production system. In this sense, if a company does not make efforts to reduce variability, it "pay for", with low process output rate (throughput), high lead times, ability to waste and high levels of WIP.

Regarding the reduction of variability in the arrival rate of tasks, Hopp and Spearman (2001) suggest: i) improved production scheduling ; ii) better shop floor control; iii) use of a pull system, such as CONWIP system (Constant Work in Process). With regard to reducing the variability in the process, the literature provides methods as operator training on tasks, use of standardization activities and the use of automation tools. Improvement in average time to set up and repair in time between failure and defect rate are targets of a series of modern manufacturing management paradigms, such as Lean Manufacturing (WOMACK et al., 2000) and Quick Response Manufacturing (SURI, 1998), among others.

The Methods, for achieving these improvements, treated in the literature (GODINHO;UZSOY, 2009), such that: The SMED system (Shingo 1986) for reducing the averaging time set up; the so-called Total Productive Maintenance – TPM to improve the average repair times and mean time between failures; and methods such as SPC (Statistical Process Control), Six Sigma and TQM (Total Quality Management) to reduce the average rate of defects.

2.2 Factory physics

According to Pentillä (2005), Factory Physics approach establishes a set of laws to explain the behavior and the relationship between variables on the shop floor by providing tools for analysis of existing operations, to project possible improvement efforts, and trade analysis offs. This approach, according to Hopp and Spearman (2001), has three main properties: it is quantitative, simple and intuitive, providing this way important insight into manufacturing.

Standridge (2004) states that the Factory Physics approach provides a systemic overview, expressed through some basic laws of behavior of a system. According to the author, he points out that this approach has the potential to contribute to the achievement of studies using simulation.

3. Methodology

3.1 Factory physics approach

As the chapters 8 and 9 of the book Factory physics, we considered the model at steady state, so that the application of the formulas is feasible, considering a queuing system.

The approach of this study is to model the performance of the production system over a 05 years' time in 2 and 2 months.

The Continual improvement policies are modeled as reductions in mean and variance for the studied parameters: variability of the rate of arrival of orders in the system; process variability - which is formed by three types of variability: natural variability of the process, repair time and the variability of the machines set up time; mean time between failures machine; average time of repair of the machine; and mean time to up the machine set.

In each period, the new values of the parameters calculated based on the improvements implemented in the previous period and the equations of Factory Physics used to propagate the effects of improvements in performance measures for the studied system (WIP and Utilization).

3.2 The model

The study model considers a manufacturing system with only one-server and with time of arrival times and general processing, which can be represented as a G / G / 1 queue.

We assumed that the natural process time (time required to process a task that excluding any process variability) have to average and t_0 standard deviation e_0.

The average effective time devoted to process a flawless piece as t_e, and its variation coefficient c_e.

It is assumed that tasks arrive at the workstation batch size L and the average time among arrivals of these lots have t_a and coefficient of variation of the arrival rate c_a.

The rate of arrival of the batches λ is the inverse of the time among arrivals, resulting in:

$$\lambda = \frac{1}{t}$$

(Equation 1)

The average time to process, a batch of parts given by Lt_e, and the average server *Utilization* given by:

$$u = \frac{LTe}{Ta}$$

(Equation 2)

The average cycle time is another performance measure of interest in this study. For G / G / 1 queue there is no exact analytical expression for calculating the average cycle time, but the following approach, recommended by Hopp and Spearman (2001), appears to be quite useful and can be used:

$$CT = \frac{(c_a^2 + c_e^2)}{2} \left(\frac{u}{1-u}\right) Lt_e + Lt_e$$

(Equation 3)

The work in process (WIP) calculation as a performance measure used in this study, it is givin simply by the know Little's Law:

$$WIP = \lambda \times CT$$

(Equation 4)

The effective average time (t_e) to process a workpiece it is calculated from natural process time by the addition of three effects: effects preempitivas stops, defective items, and non-preemptive. Thus, the first step for te calculation involves calculating the average value of the effective processing time, it is taking into account only the effect of machine failures. We denote this time as te_f. Following the treatment by Hopp and Spearman (2001), we assume thats the time between two consecutive failures to be exponentially distributed with mean m_f, the average time of repair m_r, and the variance of σ_r^2 repair time. This has been that the average server availability is given by:

$$A = \frac{m_f}{(m_f + m_r)},$$

(Equation 5)

resulting in:

$$t_e = \frac{t_0}{A}$$

(Equation 6)

The variance of this time is expressed in the summary table (figure 3).

They are then incorporated the effects of non-preemptive stops (*setup*), assuming as in Hopp and Spearman (2001), the set up is also likely to occur after processing of any piece with expected number of pieces between two *setup* consecutive ups like the plot of average size *L*. The average time to set up is denoted by t_s, and the variance by σ_s^2. From this, one can get the average processing time, taking into account both stops (preemptive and non preemptive), denoted by te, as:

$$te = t_0 + \frac{t_s}{Ns}$$

(Equation 7)

Its variance is also presented in the abstract formulas table (figure 3). Finally, incorporating the effects of defective items, it has the overall average effective time,t_e, where *p* denotes the proportion of defective items.

is given by:

$$t_e = \frac{t}{(1-p)})$$

(Equation 8)

The variance of the overall average effective time is given by:

$$\sigma_e^2 = \frac{(\sigma_e^0)^2}{1-p} + \frac{p(\sigma_e^0)^2}{(1-p)^2}$$

(Equation 9)

Importantly, the server capacity to be strictly greater than the arrival rate to prevent the station from being overwhelmed. Figure 01 shows the real cases (those with variety) for two environments: a) processes arriving with low coefficient of variation, b) processes for arriving with a high coefficient of variation.

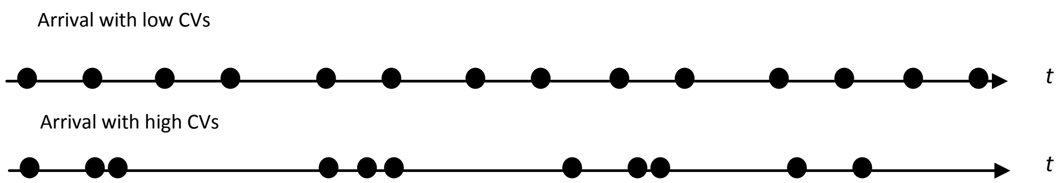

Figure 1 - arrival processes with high and low CVs

Font: Adapted Hopp e Spearman (2001)

The Figure 02 shows the propagation of variability among stations in series. Note that if the variability of a station starts is the result of the variability of arrival at that station and the variability of times.

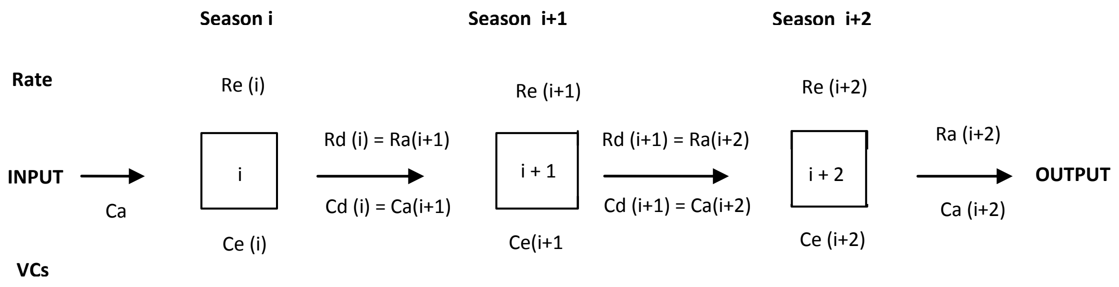

Figure 2 - Propagation of variability between series at stations

Font: Adapted Hopp e Spearman (2001)

Below the figure 3 with the summary of the formulas used by the extracted model factory physics book.

Situation	Natural	Preemptive	Nonpreemptive
Examples	Reliable Machine	Random Failures	Setups; Rework
Parameters	t_0, c_0^2 (basic)	Basic plus m_f, m_r, c_r^2	Basic plus N_s, t_s, c_s^2
t_e	t_0	$\frac{t_0}{A}, A = \frac{m^f}{m_f + m_r}$	$t_0 + \frac{t_s}{N_s}$
σ_e^2	t_0, c_0^2	$\frac{\sigma_0^2}{A^2} + \frac{(m_r^2 + \sigma_r^2)(1-A)t_0}{A\, m_r}$	$\sigma_0^2 + \frac{\sigma_s^2}{N_s} + \frac{N_s - 1}{N_s^2} t_s^2$
c_e^2	c_0^2	$c_0^2 + (1 + c_r^2)A(1-A)\frac{m_r}{t_0}$	$\frac{\sigma_e^2}{t_e^2}$

Figure 3 - Summary table of formulas

Font: Adapted Hopp e Spearman (2001)

As the purpose of this article is to study the impacts of continual improvement projects on five parameters on performance measures WIP and Utilization, a mechanism that models continuous improvement is necessary. The following will be presented used parameters in the model.

3.3 Model Parameters

The parameters used by the simulated model were collected at a company located in the metropolitan area of Belém- PA. Its belongs to the automotive industry, which will be called this study by ABC company.

It is important note that due the high demand and growth in this sector, over the last four years there a has been a 60% increase in production vehicles/day at the plant, impact need for high levels of operational availability and reability (CARVALHO, 2015).

Besides that, this study presents strong contribution to the automotive sector, because this sector has been suffering serious problems. According to statistics released by the National Association of Vehicle Manufacturers (ANFAVEA), vehicle production in Brazil in 2014 retread 15,3 %, while the initial estimate was down 10%. Sales followed the negative movement , falling 7,1 %. With the end of the tax collection reductions on Industrialized Products (IPI) and high inventories, layoffs have been recurrent (ANFAVEA, 2015).

Therefore, the results this paper can represent strong relationships in real cases. Because of the need for comprehensive data collection in the company, the study is considering only a number in the machine. The default period was 2 months. The system is simulated for five years, considering that the company works 120 hours per month, or 1440 hours/year. The annual demand is constant 12.000 pieces per year. For the time among arrivals, it is considered to be exponentially distributed and variation coefficient, equal to 1, with a natural processing time per piece equal to t_0 = 4 minutes and c_0 = 1. To start the simulation, the average time between failures was m_f = 8200 minutes, the mean time to repair equal to m_r = 260 minutes. And the average setup time t_s = 120 minutes.

The cases to be simulated in the following environments:

a) environment without any improvement;
b) environment with 50% improvement in process variability;
c) environment with 50% improvement (reduction) in the variability of the time among arrivals;
d) environment with 50% improvement (increase) the average time among failures;
e) environment with 50% improvement in mean time to repair;
f) environment with 50% improvement in the average setup time.

4. Results

4.1 Impact of the implementation of improvement projects and batch reduction

In this section, we will display the average WIP behavior resulting from the implementation of improvement projects presented in the previous section. Simulations were performed for three batch sizes (60, 160, and 500) in this study to analyze the effect in *work-in-process* (WIP).

Figure 4 shows the average level of WIP behavior over time resulting from the implementation of projects aiming 50% improvement in the five parameters studied for a lot size of 160 pieces. For this analysis (Figure 4) only one WIP value is used for each case considered. This value corresponds to the value at the time, it becomes constant (i.e. after improvement efforts have reached their ultimate goal). Simulations like this were conducted to examine the other two lots (60 to 500 pieces).

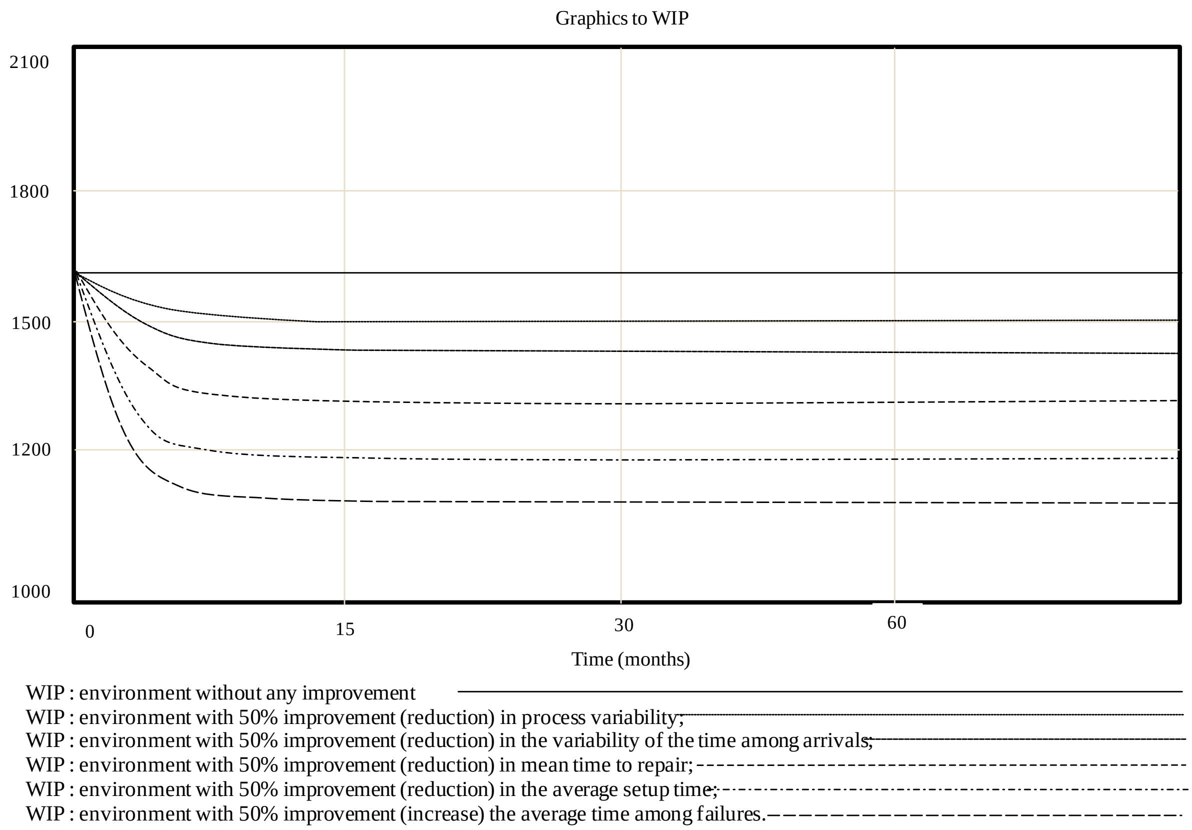

Figure 04 - Average WIP behavior resulting from implantation of 50% improvement

Font: Authors (2015)

Table 01 and Figure 5 show the impact of the implementation of the WIP and the variation in improvement projects batch sizes.

Batch size	WIP Without any improvement	WIP – Reduce of 50%				WIP – 50% of increase time among failuress
		In process variability	In the variability of the time among arrivals	In mean time to repair	In the average setup time	
60	2520,54	1658	2460,5	2032,75	783,5	2152,5
160	1660,47	1029,5	1029,5	1276	1037,35	1327,5
500	2613,4	1782,5	2512	2021,5	2354,45	2117

Table 01 – WIP after the implementation of the 50% improvement projects (batch 60, 160 e 500)

Font: Authors (2015)

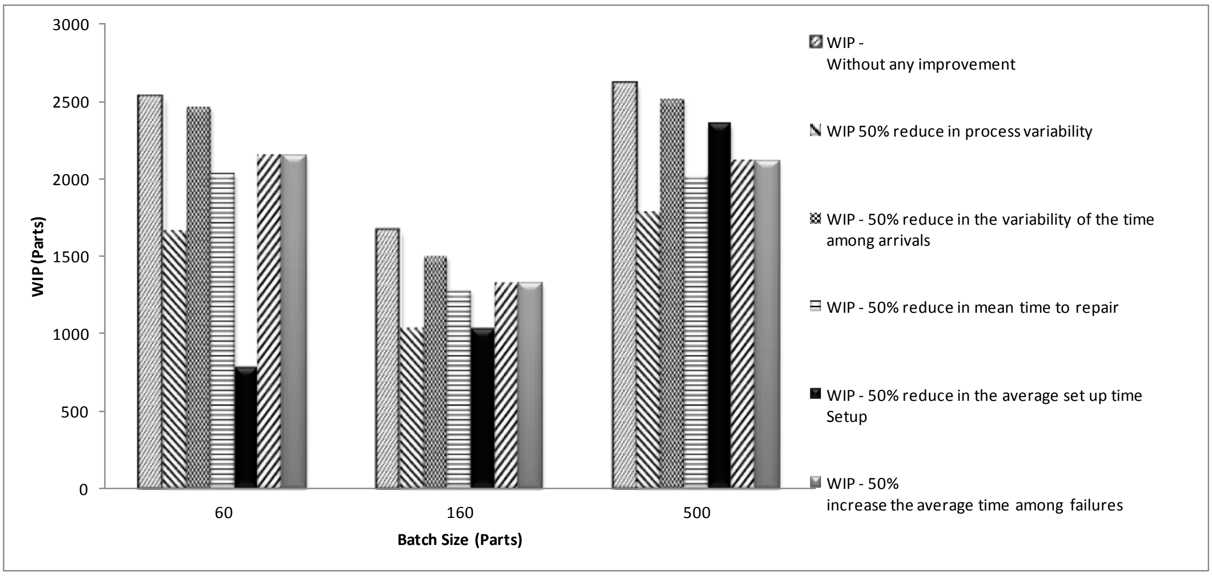

Figure 5 – WIP impact on reducing the size of lots and the implementation of the proposed improvements

Font: Authors (2015)

The results show that:

For a large batch size (500), 50% reduction in process variability is the program that contributes to the reduction of WIP (31.8% reduction), followed respectively by the following programs: 50% improvement the repair time (22.65%), 50% improvement in the time between failures (18.99%), 50% improvement in setup time (9.91%) and improved variability of arrival (31, 8%).

We observe an important fact, which validates the application of the formulas and the use of little law, which according to lot size is reduced, the importance of improving the set up times increases. For a batch size of 60 parts, 50% improvement in the program set up times get the best results regarding the reduction in WIP (68.92% reduction), followed respectively by the following program: a 50% reduction the process variability (34.2%), 50% improvement in repair time (22.65%), 50% improvement in the time between failure (18.99%) and 50% improvement in the variability of arrival of orders in the system (3.88%).

Table 2 and Figure 6 show the impact on the utilization of reduced batch size and programs to 50% improvement.

Batch size	Utilization without any improvement	Utilization - Reduce 50%				Utilization – 50% of increase time among failures
		In process variability	In the variability of the time among arrivals	In mean time to repair	In the average setup time	
60	91%	91%	91%	86,42%	76,15%	86,94%
160	78,9%	78,9%	78,9%	73,88%	69,88%	74,40%
500	68,38%	68,38%	68,38%	65,89%	65,89%	66,42%

Table 2 - Utilization after the implementation of the programs for 50% improvement (batch sizes 60, 160 and 500)

Font: Authors (2015)

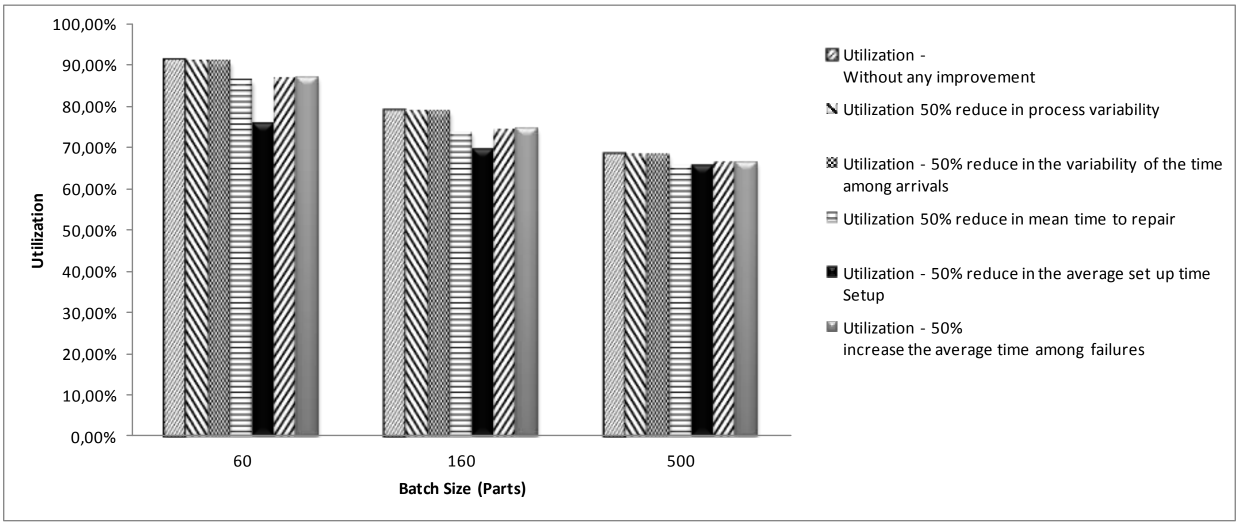

Figure 6 - Impact when using the reduced lot sizes after the improvements implemented 50%

Font: Authors (2015)

The results show that:

1) Both variability reduction projects (process and rate of arrival of orders) have no effect on *utilization*;

2) For large batch size (500), the *utilization* is largely unaffected by all improvement projects covered in this study. Projects that provide greater reduction in average levels of *utilization* are the projects to 50% improvement in setup times and repair, providing 3.64% reduction in the average *utilization* level;

3) For sizes smaller lots (eg 60), the project to 50% improvement in set up times has a strong impact on reducing the average levels of *utilization* (16.32% reduction), followed by the project to reduce 50% in the time to repair (5.03%).

4.2 Relationship between the tools and manufacturing management philosophies with the model results

In this section will be considered the model results with the use of tools and management philosophies.

The improvement project in the variability of arrival of orders of production had little impact on reducing WIP. These results provide support for all literature which advocates the importance and necessity of reducing variability projects such as, for example, the strategy Six Sigma and reduced set-up programs, such as program SMED (Single-Minute Exchange of Die) conceived by Shingo (1986).

The proposed implementation of improvement projects provide support to the literature on the Toyota Production System / Lean Manufacturing, which argues that substantial improvements in business should be achieved through small efforts of continuous improvement made in all company sectors with the active participation of all employees. These results also illustrate why a large part of modern management practices focus continuously improving as a way to achieve competitive benefits by reducing WIP.

We observed that there are convex relationship between batch size production and WIP. This is similar to the relationship between lot size and lead time (Karmarkar et al., 1985b), it is known in the literature on Queuing Theory (HOUSTON, 2006). From this relationship, it can be concluded that only efforts to reduce the batch size do not guarantee, by themselves, reducing WIP levels. To achieve reduction of WIP, Continual Improvement projects can provide "path" alternative.

We can also notice the importânca to know the relationship between lot size and WIP before determine how much to reduce the lot size: In some cases, major reductions in lot size, even together with some improvement project continuous, can in fact contribute to an increase in average levels of WIP compared to a larger batch of parts and no implanted improvement. These results provide support to the philosophy Quick Response Manufacturing (QRM) proposed by Suri (1998), which states that production lot sizes in one piece, as advocated in the literature on Lean Manufacturing actually contribute, in most cases, to increase average levels of WIP and lead time.

5. Conclusion

This study presented a simulation model in a production environment with single machine and with multiple products, so how to analyze the implementation of five different continuous improvement projects, impact the average levels in *work in process* (WIP) and the *Utilization* in a manufacturing system.

Whereas large batch production, reduction of process variability contributes largely to reducing WIP. According to the production lot sizes are reduced, the importance of process variability decreases. Thus, the improvement projects in time to set up becomes the program that contributes to reducing the average levels of WIP.

As the implementation of continuous improvement projects in *Utilization*, we showed in this study that when large batch sizes are used all evaluated continuous improvement projects had little or no effect on the average level of system use. This conclusion is also valid for the implementation of small improvements in several parameters at once. As smaller lot sizes are used, improvement programs set up have the best result with regard to reducing the average levels of system Utilization. Furthermore, according to the batch sizes are reduced to average use increases. In these cases, investment in set up reduction projects have proven to be the best alternative to trying to maintain low utilization levels while the batch size reductions are made. These results therefore also provide support for all the literature that argues for the importance and the need to reduce set up programs.

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