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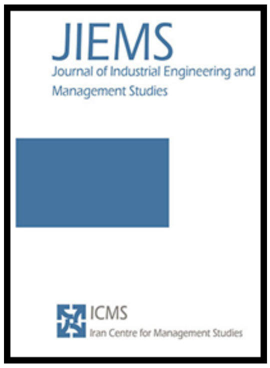

Cycle time reduction for productivity improvement in the manufacturing industry

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Abstract

Cycle time is one of the viable parameters which needs to be optimised as much as possible whenever the manufacturing industry is trying to improve efficiency, cost base and customer responsiveness. This systematic study presents on the reduction of cycle time for productivity improvement in the manufacturing industry. In industries, cycle time should be focused due to the high need of balancing man, machine, materials, methods and management. It must be renowned that the reduction of cycle time is not an easy task. Productivity improvement process involves many factors in achieving the maximum reduction of unnecessary time for higher improvement. The appropriate approaches to be implemented includes lean manufacturing tools, value stream method, method-time measurements, just in time for inventory control, motion study, process study, VAT plant classification, total productive maintenance, improved MRP (material requirements planning)-based production planning, theory of constraint, linear programming and other simulation related techniques. The V, A or T types of plant classification can also be classified using optimisation production technology (OPT).

Keywords: Cycle time reduction; Takt time; Synchronous manufacturing; Productivity; Manufacturing industries.

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1. Introduction

In many sectors, there are several ways to improve productivity. Higher productivity mostly comes from mass production. There is the formation of mass customisation. Such customisation is developing the ‘new frontier’ in the commercial rivalry (Zhao et al., 2018). In order to respond quickly to the fluctuating consumer demands, there is a need for performing all tasks in a quick response. Quick response is one of the prerequisites for various manufacturers to sustain the present ‘competitive advantage’ (Zhao et al., 2018) globally. Thus,

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the increase of the quick response in fulfilling consumers' orders necessitates companies or organisations to reduce cycle time for each performed operation. Most techniques and tools should concentrate on balancing what refers to '5M' which stands for man, machine, material, methods and management. If any industry or company can manage to balance all 5M, undoubtedly this can result in win-win situations whereby the company or industry can benefit while customers also can be highly satisfied. In a systematic literature survey, there are many approaches which can be adapted to reduce wastage of cycle time with all the various parameters. One of the great and famous methods is the Toyota Production System (TPS) which is the best production improvement method to reduce wastage of cycle time.

It should be noted that, whenever production become improved, definitely it has a significant influence on productivity improvement (Sreelekshmy et al., 2013). Toyota Motor Corporation is accredited for its efforts in developing the commonly known 'Toyota Production System'. Some of the reported accrued benefits through the use of the TPS include an improvement of the quality for the produced products, reduction of cost, and the reduction of the lead time (Kumbhar et al., 2014a). In a simplified way; waste ('Muda' in Japanese) can be defined as "anything other than the minimum amount of equipment, materials, parts, space, and worker's time, which are essential to add value to the product" (Kumbhar et al., 2014a; Rajesh, 2015) as also explained by the founder of Toyota - Shoichiro Toyoda (Toyota Industries Corporation, 2019). The wastes are generated due to several performed activities for a particular process or the offered services. There are three commonly referred categories of activities, namely, "value-added activities (VA)", "non-value added" – required activities (NV), as well as non-value added – unrequired activities.

Wastes can be categorised in multiple ways. However, for this study the major wastes include overproduction, unnecessary inventory, unnecessary delay (waiting or idle times), unnecessary transportation (excess motion), unnecessary processing, unnecessary motion, defective parts, underutilisation of people (together with their skills) and underutilisation of facilities (Sreelekshmy et al., 2013). There are some activities which require a technique like SCAMPER that stands for "substitute, combine, adapt, modify, put, eliminate, reverse" (Taifa et al., 2018). Such an approach helps to substitute components, parts, people or materials so as to avoid wasting time, then combine various activities when performing multiple related tasks. Afterwards, add or adapt good practices that can help in saving time for the studied process and then modify whatever is not being performed well in the specific process. Adaptation can be made by altering the function or using other elements. Adaptation process can be performed by changing something to suit the essential needs. The SCAMPER technique progresses by putting or assigning appropriate workers who cannot waste time. Concerning to elimination scenario, this can be performed by plummeting all unnecessary elements or activities as a one way of reducing wastes. The final step for SCAMPER is reversing process which can be done by retrogressing some activities that comply with such method.

In the daily operation of the manufacturing industries especially the industries which are not amongst the world classic manufacturing industries, the long cycle time is one of the issues which is affecting their performances (Kumbhar et al., 2014b). However, nowadays several researchers encourage to integrate numerous related techniques (Taifa and Desai, 2017a) in solving industrial problems for generating optimal solutions or results which can be benchmarked from the best performing industries (Taifa and Desai, 2015b; Taifa, 2016; Taifa and Desai, 2017b; Taifa and Desai, 2017a).

The study comprises seven sections. Section 1 details an introduction about the overview of the manufacturing industries and the background of wastes in manufacturing processes.

Section 2 expounds about the general theoretical background – cycle time, takt time and cycle time reduction. Section 3 explains the systematic review of related studies which deployed cycle time reduction techniques and tools. Section 4 elucidates the provided discussion for this study while section 5 explicates the relationship between cycle time and productivity. Ultimately, sections 6 and 7 details about the potential implication of this study and the concluding remarks together with recommendations respectively.

2. Theoretical orientation

2.1. Cycle time (CT)

Multiple ways can be used in defining the term “cycle time” based on the type of company, industry, firm or organisation. Here, the authors considered two examples of organisation – manufacturing and service organisations. For instance, when defining CT in manufacturing industries, it can be stated based on the average time should it take to process a product starting from receiving of the raw materials up to when the product is complete. For service organisation or industry CT can be defined or expounded in relation to the time a customer states his or her needs (or wants) and the total time should it take to complete the requested service. This view is supported by Khan and Sharma (2014) who writes that CT can be circumscribed as the entire time to move and process a workpiece from the beginning until the end of the evidently resolute physical manufacturing process (Khan and Sharma, 2014). A manufacturing cycle comprises all activities starting the order entry stage up to shipping stage (Swamidass and Majerus, 1991). CT comprises process time during which a workpiece is processed or machined so that to bring the workpiece closer to final shape or size and delay time, in which the workpiece is spent whilst waiting to go to the subsequent step (Sreelekshmy et al., 2013). In a standard and straightforward concept, cycle time comprises both VA activities and NV activities times, e.g. order entry, inspection time, processing time, storage time, transportation time, and waiting time. Klarin et al. (2016) discuss cycle time as a production cycle time. This view is supported by Klarin et al. (2016) who write that several components form production cycle time. These include non-production time and production time. Production time can be explained in comparison to technological time, manufacturing time and set-up time, non-technological time, control time, transportation time, and packaging time. CT helps to improve the sustainability and competitiveness of an industry (Chen, 2013). Likewise, shorter CT is reported to have a great impact on the ‘operational planning in production’, and it also helps in improving the efficiency of the ‘customer order fulfilment’ (Stalk, 1998; Hopp and Spearman, 2008).

Patel and Shah (2014) define ‘cycle time’ as the time necessary to accomplish a certain task or activity at each well-defined station. Typically, there is a relationship between ‘cycle time’ and ‘service time (ST)’. The CT is larger than the ST. Likewise, Anyaeche and Adegbilero (2014) explain CT in comparison to the differences between the beginning of the particular task and completion. Additionally, CT should comprise both non-productive and productive work along with any identified ‘idle time’ (Anyaeche and Adegbilero, 2014). Furthermore, Chen (2013) explains CT as a manufacturing lead time or flow time of a given task or job with consideration to the time needed for the job to be accomplished in the particular industrial unit. Thus, mathematically ‘cycle time’ can be given by equations (1) and (2) (Patel and Shah, 2014).

$$\text{Cycle time} = \text{Service time} + \text{ Idle Time} \quad (1)$$

$$\text{Cycle time (CT)} = \frac{\text{Useful production time available per day}}{Output\ per\ day} = \frac{T}{Q} \quad (2)$$

2.2. Cycle time reduction

Cycle time reduction (CTR) stands in the side of minimising CT which can be done by recognising and employing more efficient and proficient (effective) techniques in accomplishing systematically defined tasks. Such a practice necessitates reducing or plummeting all the NV tasks or activities. The NV tasks or activities are activities which do not increase value or improve value to the particular product, i.e. the absence of such activities has no known effect on the produced outputs. There are numerous instances of the 'non-value added' activities to which the CT gets plummeted or removed in manufacturing industries. Such examples include machine set-up, repair due to defects, test inspection, schedule delays, et cetera. The process of reducing the 'cycle time' can have a substantial influence on the 'bottom line' of a company if the appropriate techniques become instigated (Kumbhar et al., 2014b). Kumbhar et al. (2014b) explain cycle time reduction on how it provides tremendous benefit to any manufacturing company. The process of reducing cycle time means a decrease of the non-value added activity (Hetzel, 1993). By doing so, there are some of the benefits from this reduction as follows: reduced cost, better-quality communication, lead to rationalised processes, improve on-time delivery (dependability), upsurge throughput for the company, lessen the process variability and enhance schedule integrity (Leachman and Ding, 2011; Kumbhar et al., 2014b).

The research by Chen (2013) provides insightful concepts on the importance of being able to shorten the task or job cycle time for the industry. The pointed out reasons include: first; each received order or job epitomises a great 'opportunity cost' for the particular industry or firm, and in case that there is a long CT, then this implies that it is challenging to change the "opportunity cost into profits" in the short-range (Saraswat et al., 2015). Second; lengthy job 'cycle times' have a negative impact on the accretion of the 'work-in-progress (WIP)'. Such a situation result to complicate or challenge the entire management of the shop floor.

2.3. Takt time

Takt is a German word for rhythm. Takt time (TT) deal with how frequently the product or part is obligatory needed usually by the buyer (Kumar and Kumar, 2014). Again, TT is defined as a "total cycle time in which the product must be produced to meet the customer demand" (Prashar, 2018). Takt time (time/piece), can be calculated using either equation (3) (Kumbhar et al., 2014b; Saraswat et al., 2015) or by using equation (4) (Prashar, 2018).

$$\text{Takt time} = \frac{\text{Available Operating time (sec/day)}}{\text{Daily Demand (pieces/day)}} \tag{3}$$

$$\text{Takt time} = \frac{\text{Available time}}{\text{Customer demand}} \tag{4}$$

Jovanovic et al. (2014) explain the total 'manufacturing cycle time' in Figure 1 as a highly multifaceted extent formed with a variety of multiple elements both measurable and non-measurable components. Both components must be identified systematically. The CT duration entails both productive time (PT) and non-productive time (NPT). The PT means the technological operations connected to vicissitudes in the shape of the workpiece and the specific property, while the NPT comprises all processes related to conveyance and control (Patel and Shah, 2014). Figure 1 shows various manufacturing cycle time factors. These factors should be reduced as much as possible in the manufacturing industries.

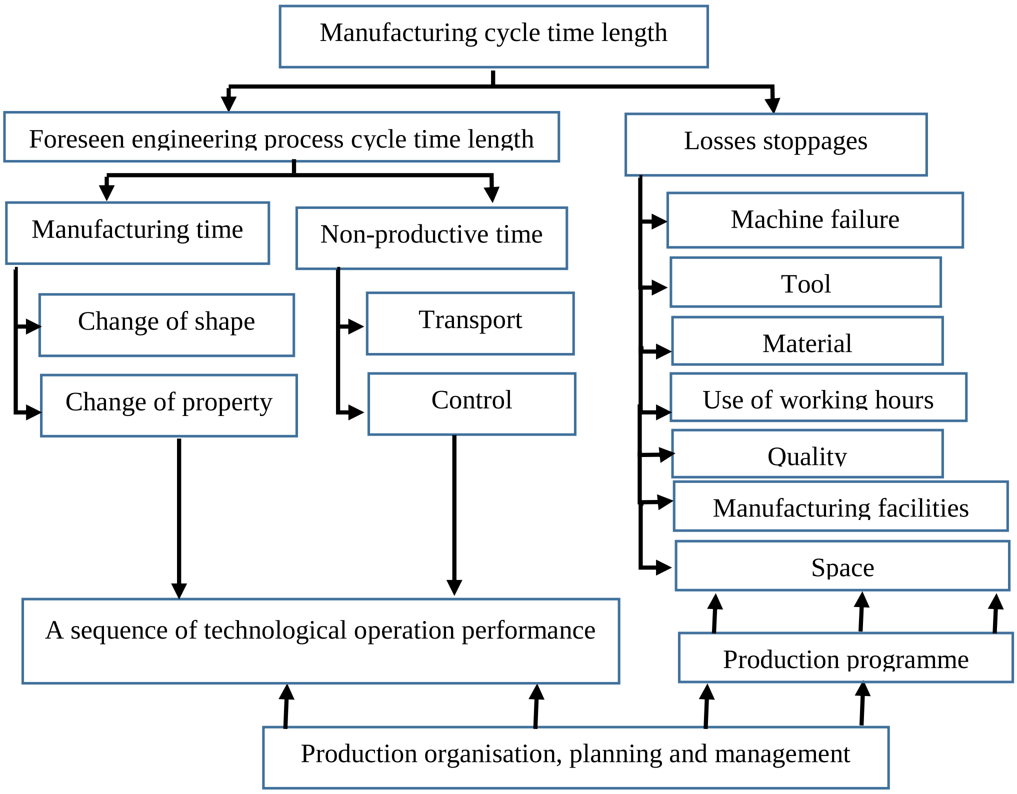


Figure 1. Several factors on manufacturing cycle time duration (Jovanovic et al., 2014).

3. Applied methodology

3.1. Systematic review

Reduction of the manufacturing cycle time for the aim of improving productivity in manufacturing industries necessitates to have and consider various methods which can be implemented depending on the situations of the particular industries and the type of products being manufactured. Various researchers (e.g. Kumar et al. 2014; Chandegra and Deshpande 2015) used different methods depending on the product type, type of industries and how easy the pertinent data could be collected and analysed through the dedicated and used techniques. The commonly methods which have been used include value stream method (VSM), assembly line balancing, method-time measurements (MTM), lean manufacturing tools, critical chain project management, Just In Time, cellular manufacturing approach, total preventive maintenance (Kumar, Shetty, and Rodrigues, 2014; Chandegra and Deshpande, 2015) and other relevant techniques. Table 1 summaries the used methods and states numerous advantages for each specific technique which are for reducing cycle time in various industries.

The accomplishment of cycle time reduction requires to go through numerous methods. There are no limitations on what methods should be used to reduce cycle time in manufacturing industries. Murali and Nagaraja (2014) defines VSM as among the lean tools which deploy a 'flow diagram' whilst detailing each stage of a specific studied process. The VSM act as a central tool for recognising the available wastes in the particular process. Also, VSM details how to plummet the process 'cycle times', and ultimately the same help to execute an improvement of the process.

Table 1. Overview of the various methods deployed for cycle time reduction.

Methods suggested and used	Advantages to be achieved	Source
• Total Productive Maintenance (TPM) approach • 5S methodology • Kobestsu Kaizen (KK), • JishuHozen (KK), • Safety Health and Environment (SHE) • Education and Training (EandT) Pillars	• Improve the effectiveness of the production by finding and removing the majority of the 'production losses' in the production system by involving all workers.	(Chandegra and Deshpande, 2015)
• Reduce WIP (Work In Progress) • Process steps reduction • Lot size reduction • Decrease the non-value added operations • Fine tuning	• Helps quickness in responding to the altering demands from the potential customers. • Helps to speed up product launching. • It assists in saving money by plummeting the WIP • Upsurge Yield • A manufacturer can receive 'quicker feedback' for the process capability which can help in improving the overall process • Helps savings after performing incremental development: o Better-quality employee productivity, o Improved equipment utilisation o Abridged process control measurements and non-productive tests.	(Patel and Shah, 2014)
• Lean manufacturing • Just In time inventory control • Cellular manufacturing approach • Value Stream Mapping (VSM) • Removal of non-value added activities (NVA)	• Reduced cycle time, the lesser load on the workers/operators rule out the scope of fatigue to a great extent, increased efficiency, increased production and capital benefits.	(Khan and Sharma, 2014)
• Lean manufacturing techniques • Method Time Measurements (MTM) • Lean balancing	• Improve efficiency • Improve productivity • Improve cost base • Improve customer responsiveness	(Kumar and Kumar, 2014)
• Lean manufacturing techniques	• Improved total productivity • Improved quality • Helps to reduce the manufacturing lead time • Helps to reduce the amount of required floor space • Helps to increase the flexibility in reacting to changes	(Sreelekshmy et al., 2013)
• Implementation of lean with the focus on Enterprise Resource Planning (ERP)	• Reduction in work-in-progress inventory • Increase in efficiency	(Rajenthirakumar et al., 2015)
• Value Stream Mapping (VSM) • Critical Chain Project Management	• To improve efficiency • Improve Cost base • Improve Customer responsive	(Arvind and Gunasekaran, 2014)

• HEIJUNKA order production consistently, connecting both 'workload levelling' and 'line balancing.'	• HEIJUNKA assists to improve the flow of the materials within a short time for the specific 'assembly line'.	(Vignasathya and Bhaskar, 2012)
• Process analysis • Work analysis • Motion analysis or Method study	• Upsurge total throughput • Helps to abridge cost • Improved communications • Rationalised processes • Increase dependability (on-time delivery) • Helps to abridge the 'process variability.' • Schedule integrity	(Kumbhar et al., 2014a)
• Value Stream Mapping (VSM)	• Reduce production lead times • Reduce costs • Improve customer service levels	(Saraswat et al., 2015)
• Value Stream Mapping (VSM)	• Identify the bottleneck operation line • Reduce waste • Increasing productivity in the manufacturing line	(Murali and Nagaraja, 2014)
• Improved MRP(Material Requirements Planning)-based production planning	• On-time delivery, and • Minimising schedule costs	(Agrawal et al., 2000)
• Implementation of lean manufacturing tools, i.e. Value Stream Mapping (VSM)	• Reduction of lead time • VSM reduce defects, • Achieving higher process capability, • Quick response to consumer demand in small lots	(Venkataraman et al., 2014)
• A discrete event simulation model	• Reduce set-up time • Reduce the 'material handling time.' • Reduce machine uptime on the designated output variables of the total quantity	(Sivakumar and Chong, 2001)
• Examine a 'data-driven approach' that detects vital factors and envisages their influence on cycle time which involves modelling	• Speedup the time-to-market the product • Reduce costs • Shortening and quickening 'fault' detection • Enhance effective production-resource scheduling • Helps to achieve the 'throughput targets.'	(Meidan et al., 2011)
• Implementation of lean manufacturing tools (e.g. Value Stream Mapping (VSM))	• In general, it helps reductions in the cycle time after the implementation.	(Rajesh, 2015)
• Simulation software for modelling the fab at "Agere Systems is AutoSched AP (ASAP)"	• Lower CT helps to provide a "competitive advantage" in the given market • Helps to increase the total productivity • Helps to increase reliability • Helps to improve product or service quality	(Nazzal et al., 2006)

Various ways can be deployed to reduce CT. In general, the authors of this study have summarised phases that can assist in reducing cycle time. These phases are illustrated using Figure 2.

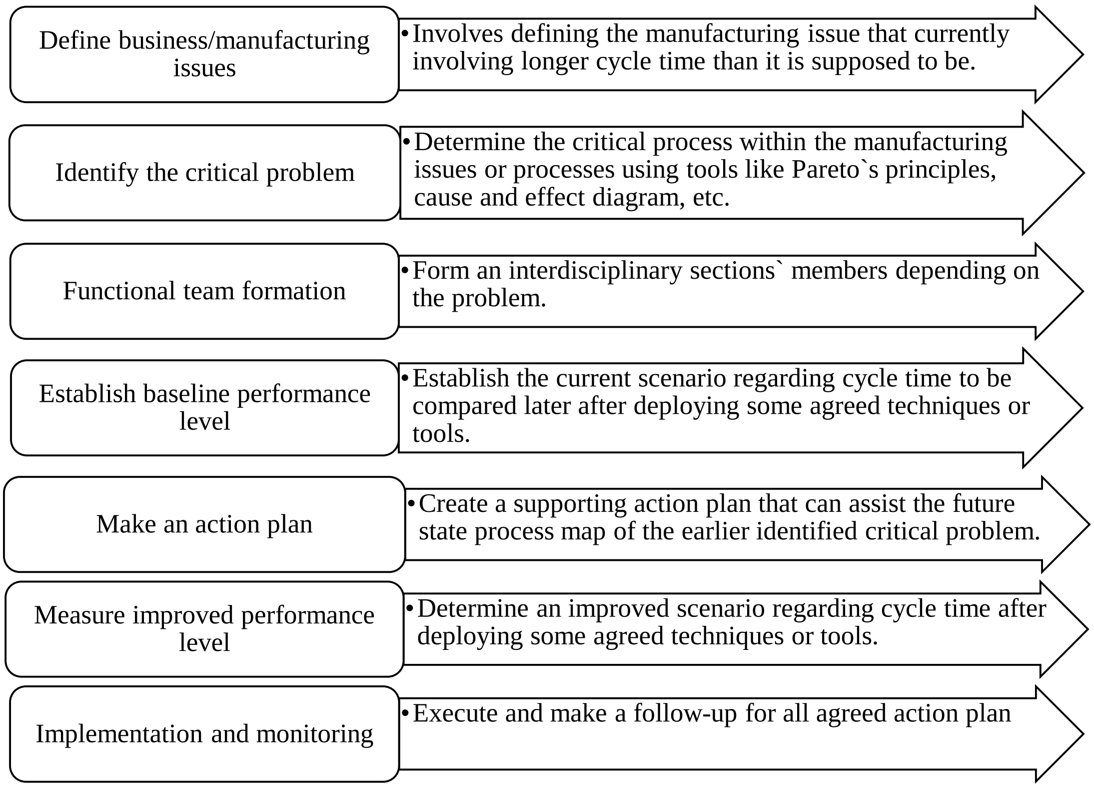


Figure 2. Phases for cycle time reduction.

3.2. The scenario of the applied techniques

Cycle time reduction in various organisations or industries, i.e. the manufacturing sector, the supply sector, service sector and the transportation sector is not a new concept. Numerous researchers already applied multiple approaches in trying to plummet the non-adding time to the final products and services. It is important to note that the duration of production cycle is considered as one of the foremost "economic and technical indicators" in assessing the performance of the production process for the given manufacturing industry (Klarin et al., 2016). Table 2 highlights a few examples of the real scenarios whereby various researchers reported successful stories regarding cycle time reduction techniques and tools.

Table 2. Some of the real examples of the applied techniques in various manufacturing industries or manufactured products.

Manufacturer type or product type	Geographical location	Applied technique or followed steps	Results reported	Source
Semiconductor manufacturer	Taiwan	• Identified controllable factors (CF) • Fitting the relationship between the job CT and the CF • Plan action • Assess feasibility	The decrease of 7% in the CT for five days.	(Chen, 2013)
CNC machining or Computer numerical control machining	India	• Taguchi method • ANOVA (analysis of variance)	Taguchi method determined the optimum cutting parameters effectively	(Mahatme and Dahake, 2016)
Automobile industry	India	• Lean principles (e.g. VSM, MTM)	Efficiency increased by 30.09%	(Kumar and Kumar, 2014)
Agricultural and construction machinery parts	Korea	• Proposed heuristic approach	The average downtime cycle time per work unit (ADCT) decreased by 40.6%	(Han et al., 2013)
Semiconductor wafer fabrication	Germany	• A new linear programming formulation together with simulation	The approach reduced cycle time by 7.37%	(Kriett et al., 2017)
Manufactures an industrial product	The United States	• Application of the principles of statistical CT control together with PERT (program evaluation and review technique) network	Helps to achieve early due date, quick response to the changing demands, and an increase in productivity.	(Swamidass and Majerus, 1991)
Military aircraft major overhaul	India	• An integrated approach of "multi-criteria decision method" (e.g. a theory of constraint (TOC), analytic hierarchy process (AHP)), and simulation.	The approach reduced over 50% in waiting time and lead time – without overtime and with overtime	(Saravanan and Thakkar, 2018)
Reduction of the production cycle time for the low and medium-low-tech companies	Serbia	• Applied work sampling technique • Three elements were observed – when a machine is operating, under preparation and not operating.	Increased total production, reduced production CT, increased overall engagement and satisfaction of the executor, increased throughput time	(Klarin et al., 2016)
The rolled sheet material of stainless steel	India	• VSM • 5S • Line balancing	Identified bottleneck processes	(Rekha et al., 2017)

4. General discussion

The primary concern is on the way to perform cycle time reduction in manufacturing industries. The ‘cycle time’ and ‘capacity analysis’ are the key to giving out the treasured and valuable information regarding the process performance of a process, firm or industry. In order to perform a cycle time reduction for productivity improvement in the manufacturing unit, it is important to gather numerous information. Such kinds of information include the means that can be deployed in determining various studied problems, the way to enhance ‘process understanding’ and how beneficial is it when it comes to evaluating the outcome of any design change that can be executed. Executing cycle time reduction by implementing the ‘process redesign’ involve the following steps: (a) elimination of activities; (b) reducing the processing time and waiting time; (c) elimination of all reworks; (d) performing all operations concurrently; (e) effecting the ‘processing time’ to activities, in place of the critical path; and (f) reducing the setup times and enable reduction of the batch size. These steps should be performed continuously rather than just once.

Through a literature survey, many authors (e.g. Rajesh 2015; Murali and Nagaraja 2014; Saraswat et al. 2015; Venkataraman et al. 2014) used lean manufacturing tools, i.e. Value Stream Mapping (VSM) to identify the waste, reduce process cycle times and ultimately implement process improvement. However, other authors (e.g. Kumar and Kumar 2014) used method time measurements (MTM) as the method to reduce cycle time in various industries (see Table 1).

In consideration to the thorough literature survey performed with the support of Table 1, it can be observed that there are techniques which follow under ‘synchronous manufacturing’ to which there are no authors used it according to the author`s knowledge. The concept is on the way to classify manufacturing firms into one or a combination of three types designated V, A and T plant classification depending on the products and processes. Implementing this concept can help to have the actual layout of the manufacturing which can perform under all well-established standards and ultimately can help to reduce cycle time. The ‘synchronous manufacturing’ was firstly introduced in the United States in the 1970s (Ronen and Starr, 1990).

The VAT classification can help cycle time reduction since it follows under synchronous manufacturing to which the entire production process work together in harmony or a synchronised way for the aim of achieving the primary goals of the manufacturing industries. Ultimately, in such a synchronous state, the emphasis is on the total system performance, not on the localised performance measures such as labour or machine utilisation. Once achieved, there is a reduction of non-added value activities which can increase the cycle time of the production in manufacturing industries if not controlled. Implementation of the VAT classification can help to have a good ‘layout’ that enhances improved utilisation of the workforce, machinery and eventually results to cycle time reduction. Such a scenario can increase the throughput and the company`s productivity improvement.

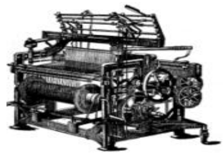
In additional to VAT classification, one can consider ‘work study’ technique as one of the approaches which can help in reducing cycle time or unnecessary activities. The study performed by Bagri and Raushan (2014) explains the term work study as “the systematic examination of the methods of carrying on activities to improve the effective use of resources and to set up standards of performance for the activities being carried out”. Then, it was mentioned about the various advantages which can be obtained by the same techniques including productivity improvement and increase in production volume (Bagri and Raushan, 2014).

Manufacturing system necessitates having some control points for controlling the flow of product through a particular system. Whenever the specific systems contain ‘bottleneck’, then the bottleneck becomes to be the best point to manage. Longer cycle time can be one of the bottleneck points for the manufacturing system; thus, it is important to avoid changing all non-bottleneck activities or operations into a bottleneck. For this study which relates to cycle time reduction, the bottleneck is any process, product or workforce which can be considered as one of the several wastes that hinder some achievements in generating the required profits for the companies. In that manner, the bottleneck can be idle time, overproduction, overprocessing, transportation issues, production of defective parts or products, excess inventory, unproductive workforce (skills) among others. The issue of ‘bottleneck’ links with the “Theory of Constraints (TOC)”. TOC mostly begin with the identification process of the system constraints. It must be noted that always there should be no hope of attaining a certain level of improvement if the constraint or a weak link is not found in the studied process or system.

The generalisability of much-published research on cycle time reduction pays much attention regarding the methods of handling it. Different methods exist in the literature regarding cycle time (see Table 1). Despite that, there are much of published research, but not much information was found on the association between industrial revolution (from “Industry 3.0 to Industry 4.0”) (see Table 3) and cycle time reduction. The world has witnessed a significant transformation in the manufacturing sector. The transformation has contributed hugely in all sectors, the manufacturing sector being the principal target. Cycle time bottleneck in many processes can be tackled by advancing the existing technology by developing a modern way of data exchange and automation in advanced manufacturing technologies through the inclusion of the “internet of things”, “cyber-physical systems”, cognitive computing, and cloud computing, among others. Table 3 highlights the key information regarding the four “industrial revolution” periods.

Starting in 2030, the “Digital ecosystem” will effectively enable value chain networks, flexible and integrated, virtualised processes and customer interface, and Industry collaboration as a significant “value driver” (Schrauf and Berttram, 2017). Similarly, Zhong *et al.* (2017) provide in-depth analysis of the work of “Intelligent Manufacturing in the Context of Industry 4.0” showing its relevance to the increase in *manufacturing flexibility*, together with “mass customisation”, improved productivity as well as better quality of the produced and offered products and services respectively. Today’s manufacturing factories or industries require intelligentization and digitisation (Vaidya et al., 2018). As manufacturers keep changing from “Industry 3.0 to 4.0”, there should be a concern in achieving mass customisation which has changed from the commonly referred to as “mass production” (Vaidya et al., 2018). The fundamental goal of every industrial revolution is based on increasing “productivity” (Pereira and Romero, 2017). Thus, Industry 4.0 can help manufacturing companies to make customised products with higher quality, short lead time (Zhong et al., 2017), and the increase of productivity. The short lead time cannot be achieved without having a short cycle time in all processes, i.e. all processes must be operated in a well-transformed manner. Therefore, the implementation of Industry 4.0 can help manufacturing companies to eliminate unnecessary activities. Industry 4.0 is not a tool on its own; rather there are tools, techniques, strategies, among others, which can help to digitalise intended goals in manufacturing systems. Formerly, mass customisation and mass production were “traditionally been at the two opposite extremes of the production continuum” (Selladurai, 2004). Nevertheless, not long ago, there has been an upsurge of momentum all over the world regarding mass customisation - a process of concatenating mass production or mass standardisation principles with “customisation” (Selladurai, 2004). It is always good to fulfil customisation requirements from customers as a means of increasing market share in a particular business (Taifa and Desai, 2016).

Table 3. The Industrial revolutions timeline.

Industrial revolution (IR) *(Period)*	**Short description**	**Example of technological development**
First IR *(Began in the late of the 18th century in England)*	Through the instigation of mechanical production facilities in virtue of steam mechanisation, steam power, water power. E.g. the first Mechanical weaving loom 1784	
Second IR *(Began in the 19th century)*	Through the instigation of mass production in virtue of mass production, assembly line (1870), steel industry, electricity	
Third IR *(Began in the 1970s, i.e. 20th Century)*	Electronics and IT application to further automate production. Computer and automation. E.g. first programmable logic control system 1969.	
Fourth IR *(Began in early 2011 to date – 21st Century)*	The modern development of data exchange and automation in advanced manufacturing technologies through the inclusion of the IoT, CPS, cognitive computing, cloud computing.	

Source: (Kagermann, Wahlster, and Helbig, 2013; Schlaepfer, Koch, and Merkofer, 2015; Simonis, Gloy, and Gries, 2016; Schrauf and Berttram, 2017; Marr, 2017). Note: CPS = "cyber-physical systems"; IoT = "internet of things".

5. The relationship between cycle time and productivity

As explained in section 1, 'cycle time reduction' is the tactic of dropping the total accumulated time foregone to accomplish a specific process with the intention of improving the company`s productivity. Many of the implemented techniques are aimed at performing the work as a standard work to provide the framework of the reduced cycle time. It should be noted that just by merely stabilising the process cannot on its own decrease the 'cycle time', but it just offers a basis to which 'improvements' can be made continuously. The term "productivity" can be expounded as the association amongst the output (products or service) and the input (resources consumed in providing products or services) of a business process or manufacturing industry (Panneerselvam, 2012). Productivity is given by equation (5). A manufacturing company which seek to keep improving its productivity must always perform continuous improvement. Productivity on its own has a so-called productivity cycle (Stainer, 1995). The cycle indicates that always there is a need for not being satisfied with whatever has been achieved in the past if someone is looking to prosper all the time. Figure 3 highlights the productivity cycle.

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} \tag{5}$$

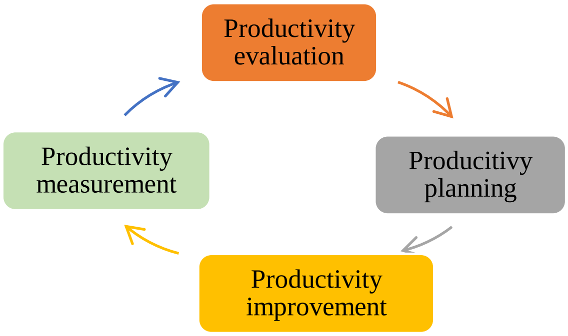


Figure 3. Productivity cycle (Stainer, 1995).

The process of plummeting the 'cycle time' cannot just increase productivity. In order to increase productivity, there should be an associated change and commitment to the workforces or upsurge of the output as the reason to increase the company`s productivity. In general, for any manufacturing to survive, the productivity ratio must be at least 1. So, the manufacturing firm must identify the way to improve productivity to the highest possible level. One of the strategies which can increase the output of the production is a reduction of cycle time so as more outputs can be produced for a short time. Achieving this to the standard way can help to improve the productivity ratio of the manufacturing industries. The influence of 'cycle time reduction' can be influenced by numerous factors - the most outstanding one being through reduction of the 'process' cycle time of the manufacturing unit. For example, when there is cycle time reduction, there is an increase in the total throughput of the particular manufacturing plant. Such output raises the number of outputs. When trying to reduce cycle time, there are numerous tools which are most important. However, with the intention of achieving breakthrough improvements, it is advocated to integrate multiple related tools and techniques (Taifa and Desai, 2015a; Taifa, 2016a; Chawasemerwa, Taifa, and Hartmann, 2018).

6. A practical implication of this study

There is no doubt that longer cycle time and takt time have a negative impact on various companies or manufacturing industries especially to the bottom line of the company. The bottom line of any industry relates to the bottom figure on an industry's income statement or the industry's net income. The systematic study has set a fundamental theoretical contribution to the numerous techniques and tools that are much acknowledged by multiple researchers on how to reduce cycle time. The provided techniques and tools once deployed effectively; there is an assurance of accruing profits. However, deployment of hybrid approaches can result in higher profits through the reduction of the manufacturing cycle time.

7. Concluding remarks and recommendations

7.1. Conclusion

The findings from this study make several contributions to the current literature. All manufacturing industries all over the world are facing global competitiveness. Such competitiveness has led manufacturers to be hard pressed on the way to minimise product cycle times which directly help to reduce the costs and meet deliveries on time. From a literature survey, many researchers are merely or not thoroughly tried to use synchronous manufacturing techniques including VAT Plant classification instead mostly have been using Value Stream Mapping with other lean tools. It is advised to seek implementation of other innovative methodologies for better comparison of better cycle time reduction technique in manufacturing Industry. Manufacturing industries face high competitiveness while at the same time the manufacturer wants to improve productivity and sustainability. Hence, the fundamental factor in achieving this is the decrease in the "production cycle time (PCT)". The achievement through reduction of the PCT can ultimately improve quick response to the customer demands. Also, reduction of cycle time bring about the momentous profits from the decrease in associated costs and "yield improvement" regardless of the type of manufacturing industry.

7.2. Recommendations and limitations

It is unfortunate that the study did not include the excluded and included criteria that used to find the stated methods, techniques or tools in Table 1. In spite of its limitations, the study certainly adds to our understanding of the cycle reduction approaches. Table 1 depicts some of the most applied cycle time reduction techniques. Some researchers prefer to use a single approach to tackling a cycle time reduction problem while other researchers prefer hybrid approaches (Taifa et al., 2018). In addition to the synchronous manufacturing approach and other identified techniques, there is a so-called Industry 4.0 which has increased great attention from numerous researchers. Industry 4.0 is also known as "the fourth industrial revolution". Thus, in implementing its concept together with intelligent manufacturing, there is a need for transforming the current manufacturing processes in an attempt of meeting the minimum requirements for Industry 4.0. Such advancement will take the existing manufacturing sector in a modernised way and will help to achieve breakthrough improvement. There is no doubt that intelligent manufacturing is recognised to be a fundamental future perspective in both sectors. The essential of intelligent manufacturing is due to that it can help to provide significant values to numerous products manufactured and offered services. All manufacturers should be ready to innovate, create, challenge and be courageous. There is stiff competition which faces all manufacturers worldwide. Shoichiro Toyoda explained his philosophy as 3Cs ('creativity, challenge and courage'). As a manufacturer, "it is most important to take the relevant factors in all situations into careful, close consideration and to have the courage to make clear decisions and carry them out boldly. The more uncertain the future is, the more important it is to have this courage" (Toyota Motor Corporation, 2003). Therefore, the systematic, qualitative and quantitative procedures are highly required for tackling cycle time problems in manufacturing industries. Moreover, further study could assess the long-term effects of the industrial revolution. Such a study should highlight the necessary techniques, tools, methods that can be deployed to plummet wastes in the manufacturing industries.

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