Optimization Processes & Analysis of Impact on Productivity: A Literature Review

Md. Shihabul Islam, Abid Hassan and A.R.M. Harunur Rashid
Department of Mechanical & Production Engineering (MPE)
Islamic University of Technology (IUT)
Board Bazar, Gazipur 1704,
Dhaka, Bangladesh.
shihabulislam@iut-dhaka.edu, abidhassan25@iut-dhaka.edu, a_rashid@iut-dhaka.edu

Abstract

Optimization in industrial systems is crucial for the competitiveness of any industry in a competitive economy. A well optimized process can ensure most effective utilization of the limited resources, prove to be cost-effective and thereby increase profitability. This paper carries out literal review on several categories of optimization, such as, line optimization, production process optimization, layout optimization and inventory optimization; and tools and processes like discrete event simulation (DES), time study, root cause analysis, ANOVA, EOQ, EPQ etc. that are used to evaluate different models and scenarios for optimizing current systems. It also investigates the most effective solutions as mentioned by different researchers in their specific situations. Then it analyzes productivity improvement through these optimization processes. Finally, it is concluded that with widespread use of such optimization techniques across different industries, organizations can better enable themselves to grow and thrive.

Keywords
Optimization, Operations Research, Productivity

1. Introduction
Industrial systems are concerned with the organization and effective utilization of available resources of modern manufacturing and process industries so as to minimize wastes of time, money, materials, and energy. It is thus clear that optimization in industrial systems is crucial for the competitiveness of any industry in a highly competitive economic environment. Consequently, how to utilize advanced modelling and optimization technologies as well as to develop new modelling and optimizations methods to design and manage these systems has attracted the interest of many mathematicians, engineers, and practitioners. A major concern in many goods-producing industries (process industry) is to improve the quality of final products. Of course, every type of products involves a different and specific process and producing rolls of paper is obviously different from producing pneumatics. However, improving the quality of products can be seen as a very similar problem for all of process industries (Kano and Nakagawa 2008). In such a type of industries, each production line follows the following schema: some raw materials define the inputs; the process is characterized by some settings such as the machines speed; and the output is characterized by some criteria on the final products (Vincent et al. 2015). So, optimization is an important topic for industries so have good quality product and better profit.

2. Line Optimization
Assembly line is component of a manufacturing plant where succession of identical products is progressively assembled. A product is any item designed, manufactured and delivered with the intention of making a profit for the producer by enhancing the quality of life of the customer. Parts can be described as a unit of production that make up the final product. There are four major process types that engineers take into consideration before selecting the right assembly layout. These are job process, batch process, line process and continuous process. Each of these production type has a unique characteristic. The job-shop process method has low production volume, but workers will be able to perform vast variety of processes. Process method is flexible and can have many different configured sequences of process. The batch process has a moderate production volume. This method allow manufacturer to produce several varieties of products either in small batches or large batches. This process type is flexible as workers only need to set-up workstations and production equipment for a specific batch. The line process has a high production volume and

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usually consist of a few major products. It is a repetitive process as all product undergo the same standardized process. The continuous process has the highest production volume and is only dedicated to producing one product. In the process layout, as the name would suggest is specialized in process task. Workstations and machineries with similar processing capability are grouped together. These group will form a department specialize in one general task such as drilling, inspection, welding and others. The group will be placed in different but methodical section of the assembly line. The intention of assembly line balancing is to ensure that an assembly line has a satisfied precedence relations and optimized measurements of effectiveness such as balance delay minimization, line efficiency enhancement, productivity increment and reduction of idle time. A basic assembly line consists of workstations connected by material handling devices. Workstation is a point on an assembly line where a certain amount of the total assembly work is performed. Each workstation in an assembly line is assigned with different tasks or operations and is set up with all necessary materials, machines, operators or even robotic arms. The basic process of an assembly line begins with a part being fed into the first workstation. After the parts have been received, the first workstation will perform the assigned operation. Once the operation is completed, the part will be sent to the next station by material handling device and the next station will perform assigned operation. These processes are repeated until the end product is achieved. The time needed to complete an operation at a workstation is called as operation time while the time required to complete all operations at the workstation is known as cycle time. The idea of line balancing was first introduced by Bryton in 1954 (Bryton 1954).

2.1 Classification of Assembly Line Balancing Problem

There are two types of simple line balancing problem (SALBP): Type-I and type-II (Baybars 1986). But based on objectives, SALBP can be classified into following categories:

- SALBP-1: Minimize the number of workstations, K, to achieve a desired cycle time, CT.
- SALBP-2: Minimize the cycle time, CT, to achieve a desired number of workstations, K.
- SALBP-E: To minimize the number of workstations, K and cycle time, CT and maximize the line efficiency simultaneously.
- SALBP-F: To determine feasibility of assembly line balance for a given number of combination of workstations, K and cycle time, CT. (Boysen, Fliedner, and Scholl 2007)(Scholl and Becker 2006)

2.2 Lean Production

Lean Production is a method to eliminate production waste and any expenditure with no value added with the basis of lean fundamentals (Elbert 2012) (Nguyen and Do 2016) (Indrawati and Ridwansyah 2015). There are seven wastes that exist in a manufacturing system as known as "Muda" which in Japanese means uselessness and wastefulness (Baudin 2002) (Womak, Jones, and Roos 1990). The seven wastes are as follows:

- Motion: Unnecessary effort which is not related to the work and non-value added such as walking, stretching, lifting and reaching.
- Inappropriate processing: Using facilities, equipment, systems or processes which are costly or time consuming while a simpler method would suffice.
- Rework: These are action of correcting faulty such as quality defects which consumes extra time and cost.
- Waiting: Wasteful time which is non-value added and should be eliminated.
- Inventory: Excess inventory causes adverse effects such as space occupying, additional storage, extra handling cost and inhibits communication.
- Transportation: Excessive material handling of product or movement of employees which is nonvalue added.
- Overproduction: Overproduction incurred when an item is manufactured before it is needed. It creates other wastes like motion, transportation and inventory.

2.3 Karakuri

In this era, material handling is a major section in all the manufacturing industries especially for delicate and huge components. The typical material handing devices usually consume fuel or electricity. This adds extra cost to the manufacturing of the products as the demand and cost of energy resources are increasing day by day. For the purpose of solving this problem in one step of solution, Karakuri is often used to replace energy consuming material handling devices. The term "Karakuri" is a Japanese word which means "mechanisms" or "trick" (Law 2015). Karakuri is an automation mechanism that was first invented by the Japanese around 18th century with the intention to create movement in puppets.

2.4 Selected Heuristic Procedure

Assembly line balancing problem is depending on a set of complex assumptions and considerations. The solution is flexible as there is no absolute solution. Heuristic method is a technique with no optimal or perfect assurance but has been used by researchers for various case studies.

- Ranked Position Weight (RPW) technique:

The RPW technique is a heuristic procedure to select tasks to assign to workstations on basis of their positional weight (PW) (Helgeson and Birnie 1961). RPW is the total of the task processing time and the processing times of all its successors (longest path time for the corresponding task in the precedence diagram).

- Largest Candidate Rule (LCR)

The fundamental of LCR is to assign tasks to workstations based on their processing times. Preparation of a task list must be done before tasks assigning begins. The list should be arranged in a such manner that the task with largest processing time at the top of the list while the task with smallest processing time at the bottom of the list (descending order). Tasks assigning then begins in accordance to the sequence of tasks on the list.

- Kilbridge and Wester Heuristic (KWM)

The KWM is a heuristic method which has the objective to select tasks and assign them to workstations based on their position in the precedence diagram (Kilbridge and Wester 1961). The prepared precedence diagram is needed to be rearranged in a manner that tasks with identical precedence are arranged in columns.

- Number of Predecessor (NOP) method

The NOP method has been widely used in assembly line balancing. In this method, the number of predecessor of all tasks are identified and listed in ascending order in a Table. The tasks are assigned to workstations in accordance to the number of predecessors staring from the top of the Table.

2.5 Approach to Line Balancing (Kit, Olugu, and Zulkoffli 2018)

- Process study: In this stage, a comprehensive study on the current assembly line including the full process, line construction, number of workstations, number of operators and task of operators was conducted. Long processes were divided into several segments (tasks) which were feasible and convenient for conducting time study.
- Time Study: In this stage, time needed by qualified and well-trained operators to complete a specific task in an assembly line was determined. First 30-minute performance was not counted as it was considered to be a warm up section where performance could be inconsistent. A well calibrated professional stopwatch was used to measure the task time of each task. Ten sets of data were collected for accuracy. Standard cycle time and standard workstation time was calculated using the following formulas:

$$CT = \sum_{i=0}^{K} TT_i$$

$$Range = TT_{max} - TT_{min}$$

$$Allowance = \frac{CT_{min} - \sum TT_{min}}{\sum Range} \times Range_i$$

$$Standard\ Task\ Time = TT_{min} + Allowance$$

$$Standard\ Workstation\ Time = \sum_{i=0}^{K} TT_i$$

Here, CT = Cycle Time
K = Total number of tasks (For CT)
K= Total number of tasks in the workstation (For SWT)
TT_i = Task time of Task i
TT_{max} = Maximum task time
TT_{min} = Minimum task time
CT_{min} = Minimum cycle time

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$Range_i$ = Range of Task i

- Performance evaluation: Different solutions are evaluated through various measures. Some of these measures are:
  Rate of production is defined as the rate at which the product is produced.

$$Rate\ of\ production = \frac{Total\ productivity\ per\ day}{Total\ running\ hour\ per\ day}$$

Line efficiency is the degree to which the resources of the assembly line including human and capital resources are wisely and effectively used.

$$Line\ efficiency = \frac{SCT}{SWT_{max} \times K}$$

Where, SCT = Standard cycle time
SWT_{max} = Maximum standard workstation time
SWT_i = Standard workstation time of Workstation i

In case of the balancing the lamp production assembly line, at first the process and time study of the current assembly line was done. Then root cause analysis of the current assembly line found out that the assembly line has imbalance in workstation time and the operators are having uneven work load which eventually led to low line efficiency and poor smoothness index. Four alternate proposals for assembly line was then prepared based on four heuristic procedure: RPW, LCR, KWM, NOP. Same time study and performance evaluation was done four those four proposals. The summary of the findings and comparison between these proposals are given in the following tables:

	Current	LCR	NOP	KWM	RPW
Number of operator	7	6	6	6	6
Number of workstation	7	6	6	6	6
Line efficiency	66.56%	85.67%	85.67%	85.67%	85.67%
Smoothness index	108.25	38.94	46.60	38.82	38.82
Overall tasks idle percentage	4.40%	16.79%	11.83%	12.26%	12.27%
Overall tasks processing percentage	32.45%	31.58%	32.94%	31.57%	31.57%
Overall tasks blockage percentage	36.44%	3.94%	19.44%	4.92%	4.93%
Overall operators idle percentage	35.90%	25.54%	22.17%	25.56%	24.58%
Overall operator utilize percentage	58.67%	73.10%	76.25%	73.08%	74.06%
Total productivity (1 day)	258	279	291	279	279
Production rate (unit per hr)	32.25	34.88	36.38	34.88	34.88

Source: (Kit, Olugu, and Zulkoffli 2018)

	Current	LCR	NOP	KWM	RPW
Number of operator		√	√	√	√
Number of workstation		√	√	√	√
Line efficiency		√	√	√	√
Smoothness index				√	√
Overall tasks idle percentage	√				
Overall processing percentage			√		
Overall blockage percentage		√			
Overall operators idle percentage			√		
Overall operator utilize percentage			√		
Total productivity (1 day)			√		
Production rate (unit per hr)			√		

Source: (Kit, Olugu, and Zulkoffli 2018)

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From these calculations, it was determined that the NOP version of the assembly line proposal gained the highest ticks and hence was chosen as the assembly line to be implemented. This assembly line consists of three Karakuri Flow Racks which eliminate non-value-added motion, transportation and waiting, which makes it better suitable from the perspective of lean production.

2.6 Alternate Approach to Line Balancing (Choon, Olugu, and binti Zulkoffli 2018)
In this approach, the methodology mentioned in the table was used:

Phase	Objective	Description
1	Identify problems in the Assembly Line	- Detailed study of assembly line and manufacturing process flow to identify the root cause of problems.
2	Develop an improved model of the assembly line process flow	- Data collection and analysis - Productivity evaluation of current process flow - Remodel process flow for comparison with current process flow - Development of proposed assembly line
3	Evaluate proposed model of the assembly line using DES	- Test proposed assembly line through model simulation using DES software.

Source: (Choon, Olugu, and binti Zulkoffli 2018)
Formulas used in this approach for time study and weight distance analysis to develop the new layout plan:

$$R - X_{max} - X_{min}$$

$$\overline{t_c} = \frac{R(t_{cmin} - \sum X_{min}}{\sum R} + X_{min}$$

$$D_{i,j} = \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$$

$$WD_{i,j} = \sum D_{i,j} \times W_{i,j}$$

$$TS = \frac{D}{\bar{t}_{ctp}}$$

$$\bar{t}_{ptp} = \frac{D}{TS}$$

Here, R = Range
X_{min} = Time minimum
X_{max} = Time maximum
t_c = Time element
t_{cmin} = Minimum total cycle time
$\sum X_{min}$ = Summation of Minimum Time Sample
$\sum R$ = Summation of Range
$D_{i,j}$ = Distance between block i and j
X_i = x co-ordinate of block i
X_j = x co-ordinate of block j
Y_i = y co-ordinate of block i
Y_j = y co-ordinate of block j
$WD_{i,j}$ = Weight-distance between block I and j
$W_{i,j}$ = Weightage
TS = Transport speed
D = Distance
T_{ctp} = Current transport time
This approach was utilized in remodeling the process flow of a metal division assembly. First Pareto chart analysis was used to determine the product with highest production efficiency. Then time element was used to standardize the time cycle for each process to produce that product. Then the weight-distance method was utilized to develop a new layout plan using the following steps:

- Gather information of space and set current closeness factors by plotting a block plan.
- Determine the closeness matrix of each pair relative to each other.

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- Rank each block closeness factor starting from highest to lowest.
- Design a block plan and relocate workstations or departments accordingly.
- Conduct Euclidean distance analysis.
- Calculate the weight-distance.
- Choose the layout with lowest weight-distance.

Then time analysis was calculated based on distance between workstations or departments' changes after relocation. Thus, the transport time between the pair would differ. Then the theoretical transport time between the workstations or departments pair was determined. The current assembly line was modelled using DES software such as FlexSim by plotting blocks and inputting all necessary parameter. The model was simulated, and the result showed which workstations with high idle time and lead time of operation. Then, a comparison between the current assembly line and redesigned assembly line was evaluated to observe improvements in idle, processing and total run time. The improvement achieved is shown in the table below:

Current Layout Weight-Distance	10548.422
Proposed Layout Weight-Distance	7708.842
Improvement	26.92%

Source: Source: (Choon, Olugu, and binti Zulkoffli 2018)

From the results, it is clear that the model of the shop floor layout configuration yielded higher productivity.

3. Production Optimization

In production process bottleneck and uncertainty is very common. There are various types of problems that may occur in production process. If some function fails and does not work properly all other aspects of optimization fails. So, production optimization is important considering the bottleneck and the uncertainty by analyzing many things. The technique for analyzing this is to run some tests with bottleneck and uncertainty. It was viewed that batch size of 12 in bottleneck, 2 common parts and 4 common machines ensure the best outcomes of the system under the storm of uncertainties (Md Abdul Wazed, Ahmed, and Nukman 2011).

In the production optimization we are considering uncertainty. Uncertainty refers to the degree of differences between the models and their respective real values or between the estimate and their true values. Errors associated with the model itself and the uncertainties of the model inputs affect uncertainty(M. A. Wazed, Ahmed, and Yusoff 2009). Modern manufacturing enterprises are facing increasing pressure to respond to production dynamics caused by disruption or uncertainty(Koh and Saad 2003). We can consider a random production line. There could be various operation. The authors have constructed few simulation models based on the existing production layout (Figure 1) of the company. The layout is modified to introduce the common component(s) and/or process(es) in the system. Figure 2 shows the abstracted layout that incorporates commonality dimensions. Only four, among the models developed in simulation, namely the base model (Figure 1), the model with a common process (Figure 2) and component (Figure 3) and the model with both a common component and process (Figure 4) are shown. However, the models are developed in WITNESS simulation package. The models in Figure 3 are only some candidates of all layouts and are designed to investigate the scenarios. The prominent uncertainty factors (machine breakdown and quality variability) are applied separately and in combination in the simulation exercises with and without inclusion of commonalities. In this study, three factors (batch size, common part and common process) are considered and the effects of these factors on the system performance are tested. The levels of commonalities (process and component) and production batch size at blockage station are considered as a control factor or decision variable. The machine breakdown and fraction of non-conforming items are considered as a noise factor. The effects of these factors will be more realistic and mimic to the real system because the system is normally subjected to these uncertainties. By a variation in the level of the factors, the work-in-progress (WIP), that is, throughputs and cycle time, is adjusted for an optimized total cost and reasonable machine productivity. Three levels of the factors are expected to have better chance of identifying the influence of both linear and nonlinear behaviors. The ranges of these factors' levels are selected based on capacity limitation and in consultation with the engineers in the company. Batch size bears its usual meaning and its different levels are imposed only on the bottleneck facilities. The second factor, that is, component commonality is estimated to have only three levels (0, 1 and 2 for no, one and two common components in the system, respectively). The third factor, that is, process commonality is estimated to have also three levels (0, 2 and 4 for no, two and four common processes in the system, respectively). As a result, the factors and their levels are used in setting experiments. The noise factors (quality and machine breakdown) are projected to have three levels for each and the levels are selected based on the historical data. The three levels of quality (that is, defective rates) are considered as 3, 5 and 7% and the machine breakdowns are taken as 40, 20 and 10 operations. It is worthy to mention that the inspection on the products is conducted at the inspection stations only and the defective products are simply rejected. The interval of machine breakdown is measured in a number of operations. For example, the number 40 means that after 40 operations, the resource will break down. The breakdown levels are used in all machines and the quality dimensions are applied in the inspection stage. Since this study contains three control factors of three levels and two noise factors of three levels for each, (33 ´32) = 243 design points are thus required in the case of a full (or complete) factorial design. However, each experiment is simulated with nine replications (two noise factors of three levels each). The average value and its signal to noise ratio based on the settings are obtained and analyzed. Analysis of mean value, signal to noise ratio and ANOVA are used to analyze the effect of batch size and commonalities (component and process) on production throughput, cycle time and WIP quantity. Interaction effect is observed before the results are confirmed, to make sure that the characteristic of the control factors is additive. In order to evaluate the experimental results statistically, analysis of variance (ANOVA) is applied. Also, the same procedure is used to check the effect of the interaction. Statistical significance tests of effects are made at 5% significance level.

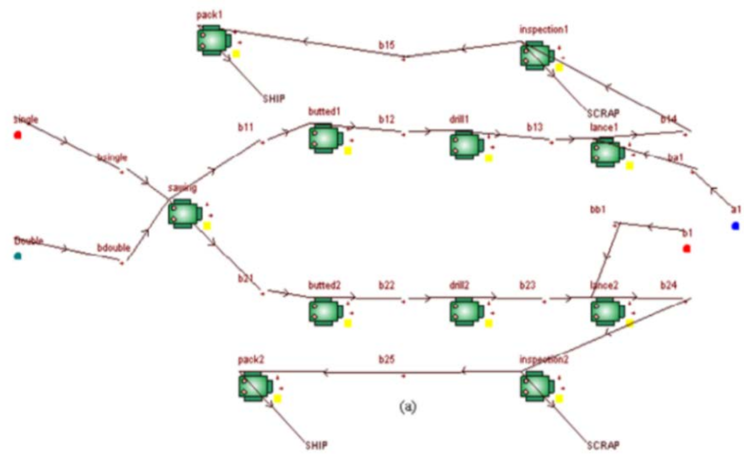

Figure 1: Base

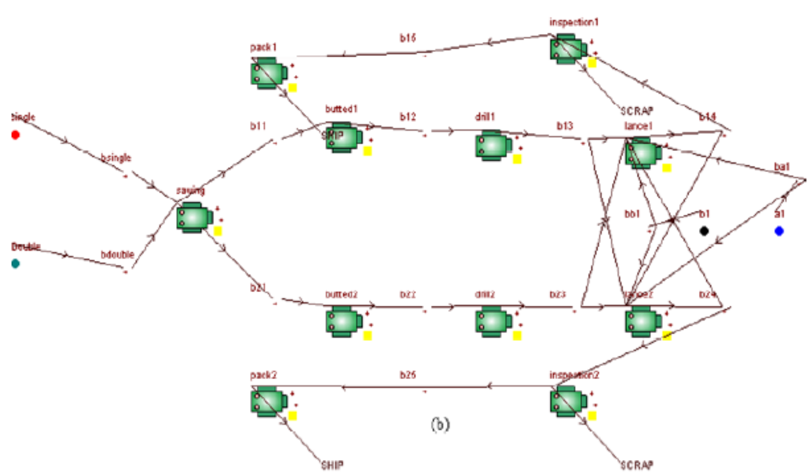

Figure 2: Common Process

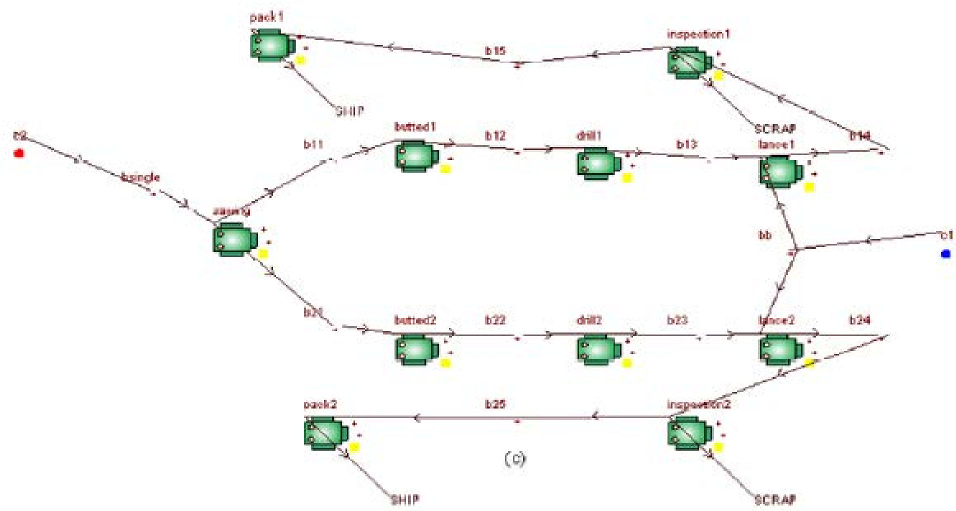

Figure 3: Common Components

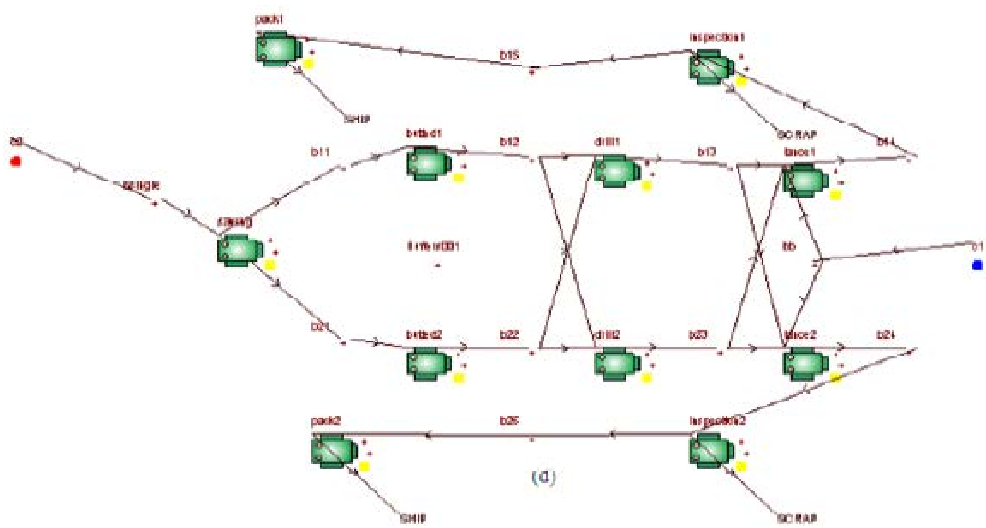

Figure 4: Both Common Process and Components
Source: Choon JWK, Olugu EU, binti Zulkoffli Z. Remodelling 2018

Use of common component and process are statistically significant. The factors have very strong impacts on the measured performances of the system by having many results. So, for bottleneck challenge and uncertainty we can overcome to get the maximum optimization in production process by using both common process and components.

4. Layout Optimization

Facility layout is an important component of a manufacturer's operations especially in terms of maximizing the effectiveness of the production process. The key of good facility layout is the integration of the needs of people, materials and machinery in such a way that it does create a single well-functioning system. An effective layout can help an organization achieve a strategy that supports differentiation, low cost or response while wrong layout planning will lead to lack of space in key areas, poor placement of key activities, excessive material handling, and increased operating costs. (Nazif A, Kamar N, Dahan SM 2016)

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This study aims to identify the line balancing efficiency of current layout focusing on process cycle time and to compare the productivity effectiveness between traditional layout and cellular layout. The methods used to archive this objective are observation and time study. Observation method allows the documentation process of the methodology in the production layout and workflow process in order to determine the time and observe the line balancing of the current layout. In the layout time study analysis is very important. It is a factor that we can optimize and then we can use it for better productivity. Waste time is undesirable. So, by time study process we can find out where the time is wasting more.

Layout is very important for production efficiency. We can use discrete event simulation by using arena to find different layout. Different layout will obviously result in different efficiency. The efficiency of the production line is closely linked with the worker and line balancing. The worker satisfaction and capability to their task at each workstation will affect the efficiency and the fairness of work distribution to the worker will make the production line more balance.

Simulation helps us to understand more about the optimization. As we see in the paper, we have achieved 3 different layouts. By considering cycle time, waste time we saw that layout three is very suitable for better production.

5. Inventory Optimization

Inventory management is a must have thing in any production plant. It manages products that comes from the plant to store and distribute to the market. Inventories are the materials stored either waiting for processing or experiencing processing and in some cases for future delivery. Inventories are treated both as blessings and evil. As they are like money placed in a drawer, assets tied up in investments, incurring costs for the care of the stored material and also subject to spoilage and obsolescence there have been a spate of programs developed by industries, all aimed at reducing inventory levels and increasing efficiency on the shop floor. Nevertheless, they do have positive purposes such as stable source of input required for production, less replenishment and may reduce ordering costs because of economies of scale. Finished goods inventories provide for better customer service. So, formulating a suitable inventory model is one of the major concerns for an industry. Again, considering reliability of any process is an important trend in the current research activities. Inventory models could be both deterministic and probabilistic and both of which must account for the reliability of the associated production process. inventories are used to serve a variety of the functions chief among which are:

- (i) Coordinating operations
- (ii) Smoothing production
- (iii) Achieving economies of scale
- (iv) Improving customer service

Two things are very important for any inventory models: when to order and how much to order and the latter is termed as economic order quantity. Traditional approaches to the problem of determining economic ordering quantities for different models of inventory have always assumed implicitly that items produced are of perfect.

Economic order quantity (EOQ) is the ideal order quantity a company should purchase to minimize inventory costs such as holding costs, shortage costs, and order costs. The goal of the EOQ formula is to identify the optimal number of product units to order. If achieved, a company can minimize its costs for buying, delivery, and storing units. The EOQ formula can be modified to determine different production levels or order intervals, and corporations with large supply chains and high variable costs use an algorithm in their computer software to determine EOQ.

The economic production quantity model (also known as the EPQ model) determines the quantity a company or retailer should order to minimize the total inventory costs by balancing the inventory holding cost and average fixed ordering cost. The difference between these two methods is that the EPQ model assumes the company will produce its own quantity or the parts are going to be shipped to the company while they are being produced, therefore the orders are available or received in an incremental manner while the products are being produced. While the EOQ model assumes the order, quantity arrives complete and immediately after ordering, meaning that the parts are produced by another company and are ready to be shipped when the order is placed.

In fact, there is nothing like a perfect production method, and it is necessary to integrate reliability into it. Any product simulation, whatever the sort. (Ahmed I, Sultana I. 2014)

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Table: Literature Focusing on Various Optimizations

Optimization Type	*Key Information*	*Reference*
Line Optimization	Upon completion of process and time study and root cause analysis, four proposals based on four heuristic methods were analyzed and the NOP version was chosen as the best one.	Kit BW, Olugu EU, Zulkoffli Z binti. Redesigning of lamp production assembly line. Proc Int Conf Ind Eng Oper Manag. 2018;2018-March(1955):3439–57.
	Upon identifying problems in the assembly line, an improved model was developed and evaluated by DES to yield an improvement of 26.92%.	Choon JWK, Olugu EU, binti Zulkoffli Z. Remodelling the process flow of metal division assembly line. Proc Int Conf Ind Eng Oper Manag. 2018;2018-March:3425–38.
Production Optimization	Common process or common components and both of them together in the simulation software were analyzed using ANOVA. How they behaved and worked together was also observed.	Choon JWK, Olugu EU, binti Zulkoffli Z. Remodelling the process flow of metal division assembly line. Proc Int Conf Ind Eng Oper Manag. 2018;2018-March:3425–38.
Layout optimization	Considering the importance of a good layout for good productivity, how discrete event simulation could work for optimizing layout was discussed. Different models were compared based upon observation method, time study analysis and worker satisfaction.	Nazif A, Kamar N, Dahan SM. Improving productivity by simulate facility layout: a case study in a car component manufacturer. Int J Ind Manag. 2016;2(June 2016):72–80.
Inventory optimization	Four key elements for improving the inventory optimization was identified. EOQ and EPQ were also analyzed.	Ahmed I, Sultana I. A literature review on inventory modeling with reliability consideration. Int J Ind Eng Comput. 2014;5(1):169–78.

7. Conclusion

In real life there is nothing called perfect system for any production system. So, there will always be flaws. To eliminate most of them is our desired goal. For betterment of the productivity we can use different methods of optimization techniques. We can also focus on different factors to enhance their ability for better productivity. Time consideration, line balancing, common process, common component, EOQ, EPQ these are the factor we should focus on. Optimizing the process, inventory, line, layout and schedule at different aspects on the manufacturing factory can greatly increase productivity and efficiency, reduce lead time, increase profit and ensure safe and sound working environment.

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Biographies

Md. Shihabul Islam is an undergraduate student who is pursuing his Bachelor of Science degree in Mechanical Engineering from Islamic University of Technology (IUT), Bangladesh. He is a Certified Supply Chain Analyst ($CSCA^{TM}$) and a Lean Six Sigma Black Belt (LSSBB). His research interests include manufacturing, lean management, optimization and six sigma DMAIC.

Abid Hassan is an undergraduate student from Islamic University of Technology (IUT), Bangladesh. He is completing his Bachelor of Science degree in Mechanical Engineering. He has been involved in several projects and research in IUT. His fields of interest include industrial safety, modern manufacturing, optimization and simulation.

Dr. A R M Harunur Rashid is an Associate Professor of Department of Mechanical and Production Engineering (MPE) at the Islamic University of Technology (IUT). He earned his Ph.D. from Dublin City University (DCU) and B.Sc. in Mechanical Engineering from Bangladesh University of Engineering and Technology (BUET). His research activities include the area of Ergonomics, Sustainable Product Design, Operations Research & Management, Maintenance Engineering, Life Cycle Analysis and Renewable Energy. He is actively involved with the activities of IEOM Society and has been serving as the Honorary General Secretary of IEOM Society Bangladesh Chapter since 2016.