Simulating operations process to achieve a hybrid optimal operational performance in supply chain scheduling: a case study

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Abstract: One of the most challenging aspects of supply chain management is synchronising job-shop production and transportation in a network to guarantee on-time delivery to distributed customers. In multiple job-shop problems, there are j jobs that need to be processed by m machines with a certain objective function to be minimised and it has been classified as a combination problem. This study uses genetic algorithm (GA) with some modifications to deal with the problem of multiple job-shop scheduling. At the end, the most suitable machine arrangement would be presented from the program due to achieve sustainable supply chain management model.

Keywords: genetic algorithms; sustainable supply chain; job-shop scheduling; just-in-time; makespan.

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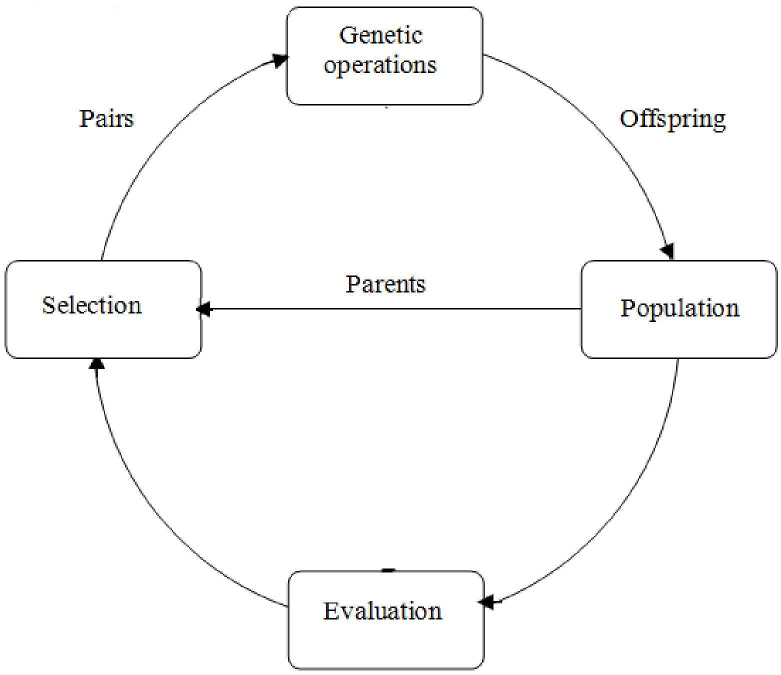
1 Introduction

Production and distribution operations are types of operational functions in a supply chain. The job-shop production and distribution can be viewed as a hybrid combination of planning, scheduling and routing problem, each particularly affected by nearly excessive combinatorial complexity. By integrating these two functions and plan and schedule them together in a coordinated manner, it is possible to achieve maximum optimal operational performance in a supply chain. Customers' heightened expectations and competition in global market have forced companies to reduce inventory levels across the supply chain and to be more responsive to customers. Integrated production and distribution planning can significantly reduce costs and improve customer service level in many situations (Bilgen and Ozkarahan, 2004; Chen, 2004; Goetschalckx et al., 2002). Joint scheduling of production and distribution operations possible and necessary and reduced inventory is resulted in linkage between them (Tajan et al., 2008; Hall and Potts 2003, 2005; Chen and Vairaktarakis, 2005; Wang and Lee, 2005; Pundoor and Chen, 2005; Chen and Pundoor, 2006; Li and Vairaktarakis, 2007). Making decisions at the aggregate planning level and detailed scheduling level often follow a hierarchical connection. Kassem and Chen (2012), Chen and Vairaktarakis (2005) and Pundoor and and Chen (2005) show that there is a significant benefit by using the optimal integrated production schedule compared to the schedule generated by such a sequential approach in the context of the models they consider. Then, having a suitable integrated production schedule at the individual order level is as vital as having a good integrated production plan at the aggregate level in order to fully understand the advantages of production-distribution integration. Because of an increasing number of problems encountered in many practical settings, it can be model as an integrated production scheduling problem. On the other side, globalisation has caused to a growing number multinational firms those have multiple plants located at different countries. This research considers a simplified version of the faced order assignment and scheduling problem by the manufacturer in the above-described supply chain. Products are produced at multiple plants and shipped to one consumer markets in these kinds of firms. Then, production costs are varying notably from plant to plant due to variations in labour costs and skills in the different countries. While many solution methods have published, the complexity of even formulating the problem has been an obstacle, even in simplifying job-shop formulations. There is a research by Chen and Pundoor (2006) that has studied multiplant integrated production scheduling problems. In their research, there is just a single machine at each plant. This research investigates extensions of Chen and Pundoor's problems with parallel machines at each plant and other time-based performance measures.

2 Genetic algorithms

Today, search algorithms are based on branch and bound methods and several approximation algorithms have developed and are in used widely. However, the branch and bound method results sometimes are unpredictable and time consuming and dependent to the size of the problem. Therefore, an acceptance result which is not far from optimal can satisfy schedulers. Meta heuristic is one of the commonly used techniques in industries and one of the search techniques that have used widely is genetic algorithms (GAs). GAs are an efficient and robust optimisation tool while there is no needs for additional information (such as convexity and derivative information) about the objective function to be optimised. As a result, the method has been applied to a considerable variety of problems, including scheduling and logistics problem. GAs can solve a problem using the principal of evolution. The algorithm will generate a new solution using genetic operator such as selection, crossover and mutation during the research process. GA begins its search space in a population and will maintain the number of population in iteration. It will generate a new schedule by selecting two individuals in population to apply crossover and mutation (Figure 1). There are many procedures that could be applied in the selection, crossover and mutation process. Some of the procedures are not appropriate for multiple job-shop problems while some of them will make the search stop at local optimal. The main goal is to find out if the idea of combining the critical block (CB)[1] neighbourhood and CB (DG)[2] distance in crossover and mutation is suitable when dealing with job-shop scheduling problems and the makespan value can be minimise (Nakano and Yamada, 1991). Result has shown that if the solution converges too quickly, it will stop at local optimal. The modification result will get a solution at least not far from optimal (Cheng et al., 2013; Kassem and Chen, 2012; Brucker, 2006).

Figure 1 The reproduction cycle



3 Multiple job-shop scheduling

The supply chain consists of a network of independent and distributed production centres serving a set of customers distributed across a predefined geographical area surrounding the nodes of the supply chain. Each production centre agrees to convey the received demands to a central planning system by joining the supply chain, which is in charge of scheduling the production on the various centres in order to optimise the operation of the entire supply chain. This means that by optimisation, the manufacturing company may no longer be the one that received the order, if this leads to a better overall schedule. The considered problem is made mostly challenging by the fact that the produced good is a material that has to be on-demand and delivered within strict time-windows to customers locations. The target of each manufacturing centre is to accept the maximum number of requests, guaranteeing the timeliness of the deliveries at the minimum overall cost. Now, supposing there are several shop floors in different location which they have produce the same products. The typical job-shop problem is formulated as a work order that consists of set of *n* jobs, each of them contains of m_i tasks. Each task has a single predecessor and requires a certain type of resource. Common objectives consist of makespan minimisation for the job sequence or achieving due dates for specific jobs (Kassem and Chen, 2012; Soukhal et al., 2005; Wang and Cheng, 2000; Jensen and Hansen, 1999).

4 Objectives

During the problem modelling, it is suitable to consider objectives and constraints as equivalent while in the problem solving they must be treated separately. Constraints are defined the feasibility of a schedule and objectives defined the optimality of a schedule during the formulation of the problem while both of them must be satisfied. Both constraints and objectives might be considered task-based, resource-based, related to performance measures, or some combination of those. A feasible and optimal schedule is able to satisfy all of the constraints (Tajan et al., 2008; Brucker, 2006).

5 Problem generation

The main task of this study is developing an effective strategy to systematically model and solve the job-shop production and supply of goods in a well-organised, reliable and systematic way, so as to bridge the gap between industrial practice and technical research. The improvement of such an effective approach also develops the sustainability of the supply chain management solutions by increasing the utilisation of equipment and by decreasing the demand on limited resources. Scheduling problems appear in different size and shapes. Usually, a small change causes in a completely new formulation. Structure of problem generators and problem definition are strongly entwined. Most problem generators include a variety of parameters with problem characteristics while parameters are frequently specific to a certain representation. One side of the problem faced by those who attempt to characterise scheduling problems is the absolute number of variations (Singh and Deb, 2014; Benedict et al., 2013; Tajan et al., 2008; Stecke and Zhao, 2007; Soukhal et al., 2005; Wang and Cheng, 2000; Storer et al., 1992; Chen, 2010; Applegate and Cook, 1991; Adams et al., 1988).

6 Case study

6.1 Data structures

Most GAs run on a population of solutions rather than a single solution. GAs process populations of strings. The representation should be a minimal, complete expression of a solution to the problem. A minimal representation contains only the information needed to represent a solution to the problem. The current problem produces a population as an array of individuals. Each individual consist of the phenotype, genotype and the fitness value. In multiple job-shop scheduling problem, there is noted the job order on each machine as phenotype, the machine schedule as genotype and makespan value as fitness. The method are used in this case study is called the permutation representation. A schedule can be represented by the set of permutations of jobs on each machine which are called job sequence matrix (Tajan et al., 2008; Brucker, 2006). In the research, the initial population has chosen randomly with generated schedules, which some of them have the shortest processing time and the longest processing time. There are many ways of choosing parents to evaluate. To get the same chance to all individuals in the population to reproduce and avoiding the premature convergence, the study randomly selected two individuals from the population and named them parent 1 and parent 2. All the jobs' numbers and their processing time are defined and fixed while research assumed there is no machine breakdown occurred. Makespan of the operation is used as fitness value and denoted as $C_{\max}$ is the time when the last operation leaves the workplace.

$$C_{\max} = \max\left(C_1, C_2 \ldots, C_n\right)$$

where

$$C_j = r_j + \sum_{k=1}^{n}\left(Wjk + Pjm(k)\right)$$

While the completion time of job *j* is C_j, the release time of job *j* is r_j, the waiting time of job *j* at sequence *k* is W_{jk} and the processing time needed by job *j* on machine *m* at sequence *k* is $P_{jm(k)}$ (Brucker, 2006).

6.2 Test problems and results

Matlab mathematical programming environment helped to develop the prototype of the GA-based hybrid scheduling strategy at this case study. There are 10 jobs and 3 machines problem with the operations order on the shop floor. The processing time for each operation has represented in Table 1. The program has run for five times using the population size = 20, the iterations number for mutation is 100 and crossover is 400. After 400 generations the algorithm was terminated. It would be concluded that the combination of genetic algorithm, (CB) neighbourhood and (DG) distance can provide a high reliable result as well as other methods.

Table 1 Processing time for each operations

	Machine 1	*Machine 2*	*Machine 2*
Job 1	17	8	6
Job 2	16	9	7
Job 3	5	15	6
Job 4	18	12	12
Job 5	19	14	8
Job 6	17	8	19
Job 7	5	7	6
Job 8	11	18	5
Job 9	16	17	13
Job 10	16	19	17

Table2 Outcomes

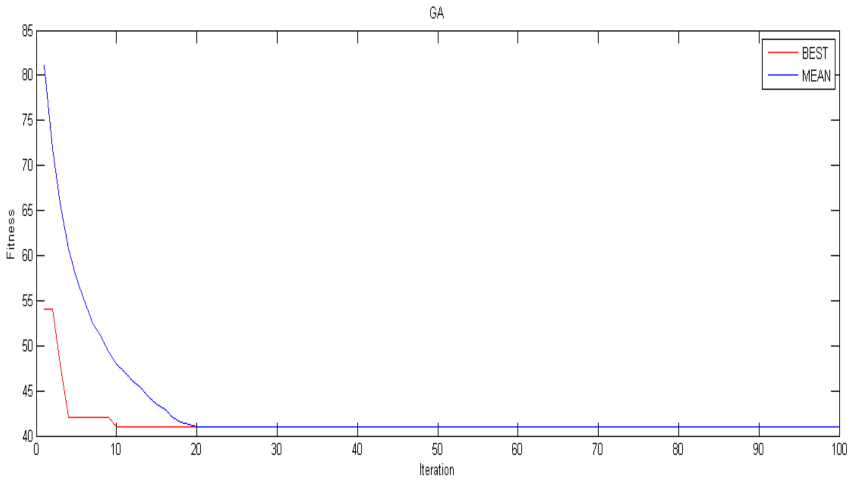
Best solution	= [7 6 2] 12 [3 10 9] 11 [1 8 4 5]
Best fitness	= 41
Time	= 3.0432

Table 3 Optimised solution

Machine = 1	Time = 41	Job = 3, 10, 9
Machine = 2	Time = 40	Job = 7, 6, 2
Machine = 3	Time = 41	Job = 1, 8, 4, 5

Both types of initial population have been applied to the data. First, the combination of schedules used which were generated using the priority rules and the randomly generated schedules as the initial population. During the five runs, the optimum before the generation exceeded 400 was resulted, and it is found the optimum value at generation 20 (Figure 2). It could be concluded that if the experiment employ the randomly generated schedules as the initial population, then only optimum value at generation would be larger than 100 with makespan value of 41.

Figure 2 Randomly initial population (see online version for colours)



7 Conclusions

The case study has offered an optimised schedule for the job-shop production system and goods delivery on a set of distributed and synchronised production centres and enlightening all the peculiarities that formulate it significantly different from other formulations of similar scheduling problems. Investigation through GA and operations model of multiple job-shop scheduling problems has provided a very well experience for the constrained combinatorial optimisation problems. The results achieved from the study confirmed that by applying meta heuristics methods like GA application, it is possible to achieve high-reliable result in almost all the same cases. GA can handle constraint, varieties of objective function and provide a flexible framework for evolutionary computation while need time to provide a high reliable results. The scheduling algorithm is guaranteed the determination of a feasible schedule for any given set of requests by combined GA and a set of practical heuristics. By comparing with exact solution methods for multi-modal activities, GA performed very well on the problems. A variety of implementations made the problem easier for GA while it made the search more difficult for the branch and bound methods. In fact, GA or any kind of hybrid model with GA variant is well-matched with more complicated problems by a mix of continuous and separate components. Meta heuristics methods are theoretically straightforward and compatible to problems with combination of continuous and separate variables while their implementation is away from trivial. Further research is recommended in a larger size to check whether a scheduling algorithm can be refined in a number of different ways, e.g., formulating more efficient crossover and mutation process.

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Notes

1 A sequence of consecutive critical operations on the same machine is called a critical block.

2 The distance between two schedules can be measured by the number of differences in the processing orders of operations on each machine.

Appendix

```
//*General overview of Genetic Algorithms*//
//* Algorithm begins *//
i = 1;
Pop (1) = random_ pop
Fitness_eval (Pop(1))
i = 2;
//* main loop of the GA *//
WHILE terminating condition == false
    P_best = findbest (Pop(i – 1)) //* elitist preservation of the best-known individual*//
    Pop (i) = select (Pop (i – 1),sel_ops);
    Pop (i) = crossover (Pop (i));
    Pop (i) = mutation (Pop (i));
    Fitness_eval (Pop (i))
    Pop (i) = Pop (i) U P_best
    i = i + 1;
END WHILE
//*Algorithm terminated*//
```

Applying lean thinking to improve the production process of a traditional medium-size British manufacturing company

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Abstract: A well-organised implementation of lean manufacturing strategy will lead to excellent operations system and continuous improvement through the removal of non-value-added activities. This case study uses value-stream-mapping to investigate non-value-added activities, simply show how lean manufacturing implementation can intelligibility result a framework of improvement. The implementation and improvements will be depicted in the area of lead time, cycle time and quality by applying lean concepts like circle-shape on production line, 5S and Kaizen team on the shop floor of a British medium-size company.

Keywords: lean manufacturing; value-stream-map; VSM; lead time; cycle-time; Kaizen; 5S.

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1 Introduction

Manufacturing is a wealth generation process which converts raw materials and information into products to supply customer needs. Manufacturing usually follows two purposes which are wealth-creation, by adding value to raw materials on the shop floor and demand satisfaction. Many manufacturing methods are available to apply to the factory shop floor to reduce waste and increase efficiency. It is not important to ask which model is the best one. The main point is that applying the most appropriate one in the current situation. Due to intense global competition and increased customer expectations, manufacturing companies require their production systems to be re-explained and re-designed in order to meet the challenges and global competitiveness of today's markets (Mehrabi et al., 2000). Therefore, practical models are essentially needed to support the re-design process of manufacturing systems. This requirement for practical techniques is well recognised in the business sector as well as in academic literature on the subject (Serrano et al., 2008).

This case study concerns on a British medium-size company shop floor. Company professionally designs and makes steel gratings and hand-railings for a wide array of industrial flooring applications from oil refineries and process plants, airports and construction companies to the smallest access walkway. Moreover, the company has this potentiality to adapt itself based on the specific customer order and it can be considered as its high level of flexibility. The main aim of this study is that responding the major concern of the company which is how to stay competitive in world-class manufacturing. Therefore, assessing the company shop floor in detail to optimise the production process would play a vital role in its future continuous improvement. The main research question is how can the company shop floor operations method be optimised? The current case study investigates the operations system and the control method used in the factory shop floor, identifies any non-value-added activities within the production line and determines the waste to reduce the lead time and increase quality.

This article was developed based on author's experiences during half-year full-time work and research at a British medium-sized manufacturing shop floor company. The job is trying to simply show some positive aspects of lean implementation on the small and medium sized factory shop floors in a short term, avoiding from complicated calculations for people who are interested to understand more about applied knowledge in the lean manufacturing systems such as students, engineers, workers, and specially some managers who believe that concepts in lean manufacturing are just appropriate for the big firms and automated ones!

2 Brief literature review

Finding a suitable tool at the first stage to analyse the manufacturing process plays a vital role in the success of optimisation. Sahoo et al. (2008) and Abdulmalek and Rajgopal (2007) believe that a successful implementation of lean philosophy depends on the close cooperation between management and shop floor personnel. They concentrated their research on the implementation of lean philosophy on the shop floor of a forging company to improve operating conditions by minimising the product defects. In the research, systematic methods such as value-stream-map (VSM) and Taguchi's methods are suggested for the implementation of lean principles. Indeed, VSM was presented by

Rother and Shook (2003) includes a step-by-step approach to transform a current manufacturing state into a lean future state, which is the basis of its success in practice. They illustrated how in recent years VSM has emerged and become the preferred method of implementing lean, both inside factories and at the supply chain level relating to those factories. They show an outline of how to do a lean transformation as a complex value stream mapping method that makes out current and future states. The results obtained from the research of Serrano et al. (2008) were maximised efficiency by using VSM and developed theoretical points to become reference for redesign techniques. Abdulmalek and Rajgopal (2007) studied the effect of the lean approach in continuous process sector. Their findings show that the applications of lean philosophy have been less common in the production sector. They have applied the lean concepts on the shop floor of a steel company to reduce cost by eliminating non-value added activities. They used VSM as a lean technique to identify waste during the production process. The research shows that using appropriate lean manufacturing tools may not only eliminate waste but also results in product quality improvement, better operational control and finally improvement in the financial area. Finally, the future state map drawn from the data and information obtained by VSM makes it easier to motivate managers to implement lean manufacturing methods in the organisation to achieve the desired results. Pavnaskar et al. (2003) propose a classification method to link all kinds of waste together in manufacturing and lean manufacturing methods. This categorised method not only enables to remove waste from operations process but also could improve the related techniques and tools in manufacturing. At the end, they recommended five comprehensive tools (Table 1) which have a direct effect on waste reduction and enable researchers and manufacturers to find connections between manufacturing problems and appropriate lean manufacturing tools for solving the problem.

Table 1 Manufacturing tools

Tool	*Definition*
Cellular layout	Re-arrangement of cells mainly in a U form.
Facility layout diagrams	Visual diagrams to present the position of machines on the shop floor.
Load levelling	Reduce idle time by assigning of work to all machines, cells or lines.
Six sigma	A philosophy of quality improvement by reducing defects.
Value stream mapping	A graphic tool to draw the situation and activities of the organization, to consider all opportunities for waste elimination and to make a decision about future improvements from eliminating waste.

Mann (2012) and Floyd (2012) believe by proving a definite roadmap by human resources management, managers can develop companies' strategies and implement them. Lean culture is a new technique to employ the talents inside the business. Implementing lean culture and involving employees in company's goals and understanding customers' needs generate distinctly more motivated employees. This interest produces more productivity and better customer service on all levels. Considering lean concept on human resources provides methods for putting more into job responsibilities in a step-by-step manner. It is also representing organisation as one where everyone is involved and will be resulted satisfied customers who want to pay more for products and services. Detty and Yingling (2000) quantified the benefits of transferring to lean manufacturing with detached event simulation and applied their model to electronic product manufacturing. The simulation methodology which they prescribed presents a reliable estimate of the resources saved on the shop floor while improving statistical time-based performance. Through the case study, they demonstrate improvements by lean philosophy simulation in transportation and inventory methods, shop floor space, manpower and equipment needs. Also in time-based performance checks such as model changeover time, order lead time and production process flow time as well as reduced unpredictability in supplier and customer demand. They concluded that the advantages of lean manufacturing cannot be achieved through simulation modelling if management principles such as organisation learning, employee empowerment systems and continuous enhancement programs are not completely adopted with the shop floor principles. Álvarez et al. (2009) illustrated how to redesign a production line with lean concepts and tools by connecting operational objectives to manufacturing system design objectives. Womack et al. (1990) explain the implementation of a lean manufacturing strategy through the elimination of non-value added activities by ascribing a strong role to the phase sequence which leads to an optimised operation process and continuous improvement. Chan (2001), Shah and Ward (2003), Lai et al. (2003) and Cagliano et al. (2004) show how lean methods contribute significantly to the shop floor operational performance. They research considered the use of VSM as a method in lean manufacturing implementation of identifying improvement points and a structure of improvement activities, in particular for a well-organised introduction of Kanban and Milkrun techniques to eliminate inefficiencies. The combination of lean methods will be a useful technique for increased flexibility and process improvement for any industry in a variety of factories and will help manufacturers to improve the materials and production flow line over a short period (Womak et al., 1990; Álvarez et al., 2009). One of the most important results from Benton and Hojung (1998) research is that a complete immigration from traditional manufacturing systems to an absolute Just-In-Time (JIT) system is not recommended and may not be successful. ElMaraghy et al. (2005) mentioned that human operators are certainly the most flexible part of a manufacturing philosophy. It is plain that people have a key role in the success of operations and manufacturing systems and generate the competitiveness of the manufacturing enterprise. It is necessary to mentioned that to achieve the benefits of lean concepts, management metrics such as instilling proper organisational values, employee empowerment systems, continuous improvement programs and setting up a consistent organisation structure, as well as installing effective management information systems, should be adopted completely.

3 Methodology

The research methodology in this case study is based on continuous investigation and improvement. Saunders et al. (2007) and Bell (2005) use continuous process through the calculation of metrics, implementation of improvement, observation of the results and new decision-making of development. To approach the highest level of accuracy, quality, reliability and credibility, the author in this case study has used multi-method data collection from observation, questionnaires, and interviews in the form of semi-structured and structured (Figure 1).

The author considered the research objective, which was a factory shop floor improvement by reducing lead time and increasing quality. The period of research was about six months.

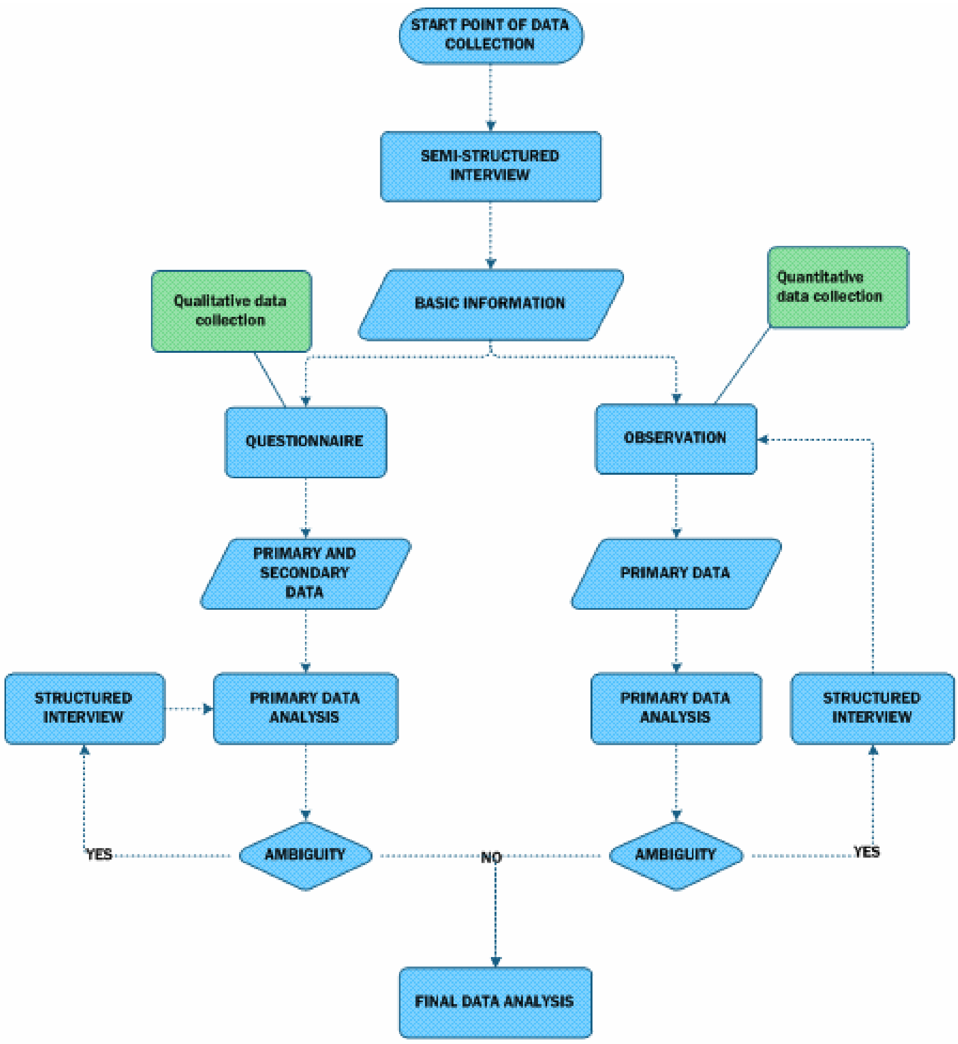
The two areas found through literature review defined the scope of the data collection in this part;

a production system and method of control

b lead time and value creating time.

The most influential image of structured observation is that of the 'time-and-motion' study expert. Author used this method to collect data to draw a current state map.

Figure 1 Research methodology (see online version for colours)



4 Manufacture and product description

A construction company ordered 1,313 flowing panel. The customer delivery schedule was based on 50% for the first month delivery and the rest for the following month. The method that was used for production and delivery scheduling was based on master scheduling. A small production line with three cells was designed to produce the new order. It consists of three stations, as shown in Figure 2.

A multi-skilled worker ran each workstation for eight hours per day to produce 35 units daily. The key activities in each workstation consist of (Figure 3):

Station 1 This workstation prepares raw gratings (image a) and welds steel sides around each grating (image b).

Station 2 two inside runners (image c) and one flap (image d) are built at this stage.

Station 3 This is the final stage, responsible for the final assembly of units coming from stage 1 and stage 2 by welding rails (image e), polishing and welding inside rails and welding inside runners (image f), polishing and welding the flap (image g) and welding the sheet (image h).

Figure 2 Company new production line map (see online version for colours)

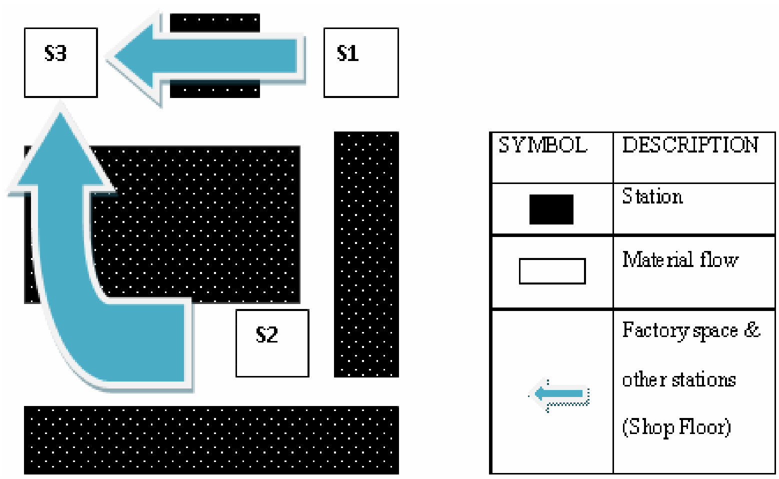


Figure 3 Key activities (see online version for colours)

4.1 Constructing the initial VSM

Theoretically, lean implementation has been accomplished during the analysis of the shortcomings of an existing process, implementation of a revised process, and following Plan-Do-Check-Assess cycles (Massei and Simeoni, 2003; Dennis, 2007). The first step in implementing lean principles and techniques on the company shop floor is identifying the value stream. VSM as a graphical tool makes it possible to show both the added-value and non-added-value activities to the operation director and thus makes it easier to make decisions about future actions (Rother and Shook, 2003; Álvarez et al., 2009). This design represented the starting point of the improvement by monitoring all the actions in the production line from start to finish. A first design of VSM was realised according to the original data from the production method and the layout, by recognising the key times for each workstation. To draw a value stream map it is necessary to select one family group of products (Abdulmalek and Rajgopal, 2007). Due to better understanding, the new production line was examined only long enough to check and measure the information related to the production line, such as the run time at each work station, the machine down time for each process, quality inspection, number of workers, lead time and value creating time by structured observation and to draw a current state map to visualise the non-value-added activities. Consistent with the production lead time and value-added time, the time line will be added at the bottom of the map. The original data and key time of each work station from the manufacturing processes which are collected by author's observation also helped in drawing the current state map. The current state map represents the starting point of all improvement. To draw the current state map or value stream mapping, the sequence of steps is shown below:

- show the materials movement between the workstations
- calculate the value-added activities (productive time) and non value-added activities (unproductive time)
- show the information flow through the operation process.

During the map drawing, the following concepts play a key role in the manufacturing process (Rother and Shook, 2003):

- *Cycle time (C/T)*: Defined as time by observation to show how long it takes to complete a part.
- *Value-creating time (VCT)*: The time spent on a unit for which a customer really wants to pay for.
- *Lead time (L/T)*: The time it takes for one piece to go from start to finish through the manufacturing process.
- *Takt time*: The maximum time that should be considered for each workstation to finish a unit. It will be calculated by the formula below:

$$\text{Takt time} = (\text{Available working time per day}) \ / \ (\text{Daily customer demand})$$

The customer demand per shift: 35 units

Available working time per day for each station: 28,800 seconds (8 hours) – 3,600

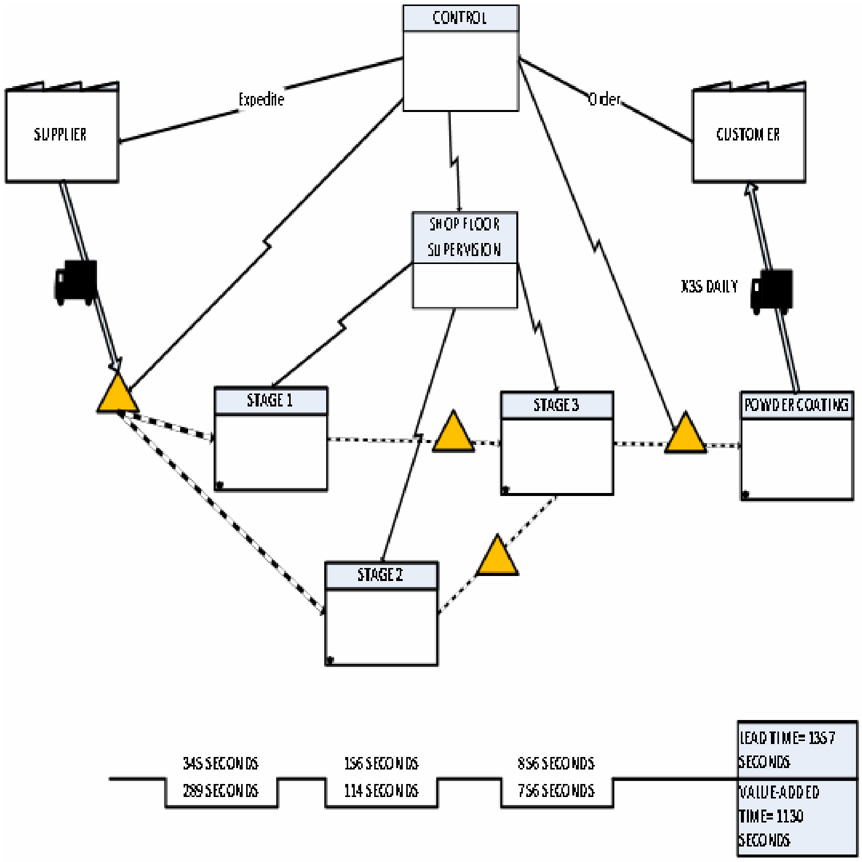
Seconds (1 hour) rest time = 25,200 seconds

$$\text{Takt time} = 25{,}200/35 \rightarrow 720 \text{ seconds}$$

This means that 720 seconds is the maximum time that could be considered for each workstation to produce one unit.

Finally, the value stream map for the current state is drawn as shown in Figure 4.

Figure 4 The present value stream map (see online version for colours)



4.2 Analysis

4.2.1 Operations system

On the company shop floor, operations control starts with a statement of demand and the role of the operations system is to translate demand into statements of capacity, materials and bought-out service requirements to see how much they cost and when they might be ready. As a result of the researches undertaken by Benton and Hojung (1998), in businesses where material requirements planning (MRP) system is used to manage manufacturing processes for production planning and inventory control, company knows the quantity of use for each contract. Then, a master scheduling method is used to plan the production period. By the bill of materials method, the company can forecast the need for raw materials, components and sub-assemblies. Workers pick up the raw materials and push the job through. The nature of the control system will reflect this significant factor. Significantly, there is no repetition on the shop floor. Moreover, Company does not have a high level of inventory and the company always keeps it to a moderate level. By consideration of Bamber and Dale (2000) findings, methods such as just-in-time, Kanban control system and push are not appropriate at the times when they might be used. The company's success is to stay with MRP as a method of production and push as control. The visual method used by Abdulmalek and Rajgopal (2007) and Sahoo et al. (2008) will push the case study forward faster. As observed from the current value map, different value-added activities in the flow line are identified and quantified in time, as shown in Table 2. It is understood that approximately 19.47 minutes (1,168 seconds), or 86.07% out of 22.62 minutes (1,357 seconds) are value-added activities in the observation, compared with 175 seconds or 13.93% of non-value-added activities.

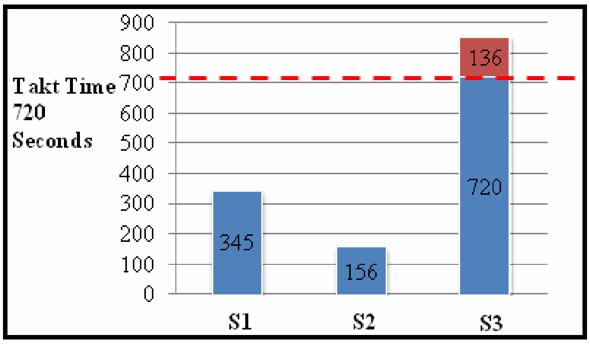
Table 2 VSM analysis report

Stage	*Activity*	*Time in seconds*	*Value-added?*	*Cycle time in seconds*
S1	Raw material transferring and preparing	51	No	
	Welding sides	198	Yes	345
	Polishing	91	Yes	
	load inventory	5	No	
S2	Reload from inventory and preparing	27	No	
	Welding	114	Yes	156
	Load inventory	15	No	
S3	Reload from inventory and preparing	26	No	
	Welding rails	180	Yes	
	Polishing and welding inside runners	395	Yes	
	Reload sheet from inventory and preparing	60	No	856
	Welding sheet	190	Yes	
	Load inventory	5	No	
Total time			1,357 seconds	

The average output per day for workstation 1 (S1) and workstation 3 (S3) is about 35 units per day, while the time to complete daily order in workstation 2 (S2) is about two times less than S1 or five times less than S3. Figure 5 shows the cycle time for each workstation and compares it with Takt time which is 720 seconds. As can be seen, the cycle time in workstation 3 is 856 seconds; 136 seconds more than Takt time and should be reduced to less than 720.

However, it is not recommended to go over production. Moreover, the cell components are not close together and stations not concentrated in an ordered sequence, as can be seen in Figure 2. Station 2 is placed in another corner of the factory and the finished units from this station have to go to station 3. However, a worker in station 2 (S2) does not concentrate on the current project only. There are not many jobs related to new orders in this station and the worker switches on to other jobs once the day's quantity is completed. In general, Company has a reasonable level of lead time. But it can reduce the lead time to reach 90% or higher in value-added activities.

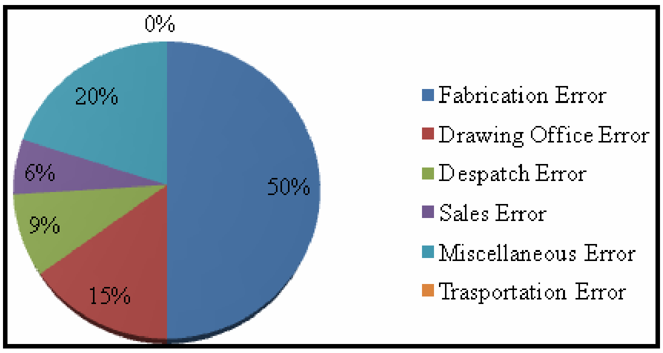
Figure 5 Cycle time (see online version for colours)



4.2.2 Quality issues

It is Company policy to adapt quality standards on the basis of customer demands. Figure 6 reports the percentage of different types of error during the eight months of 2011. The greatest percentage comes from fabrication error, which is directly related to the production process, although Company believes that product quality is very high and the level of scrap is low. Generally, the company's claim could be considered valid, in terms of the company's quality scale but it has a level of scrap that the company's target is to reduce as much as possible so as to reach the highest level of world class manufacturing standards in quality.

Figure 6 Types of company error (see online version for colours)



On the shop floor, the operations director has overall responsibility for the quality policy. All employees contribute to the Company quality standards individually. Indeed, there is a two-way bridge between the operations director and the shop floor workers which keeps quality at an acceptable level.

5 Results

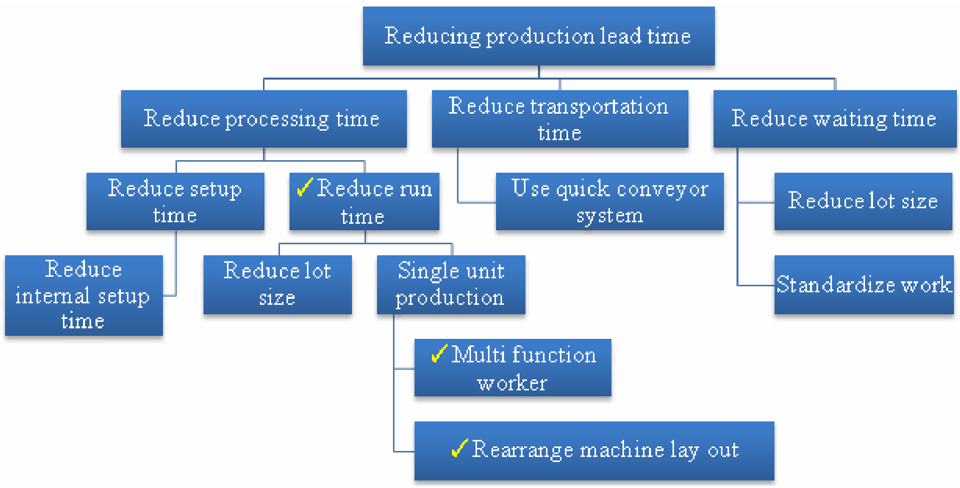
From the case study, a researcher can draw conclusions and make recommendations for practitioners to facilitate the practical use of a VSM and identify the main theoretical points to be refined and reinforced before it can be converted into a technique of reference for redesign manufacturing systems. The main goal of this research is to find a way for the company to continuously improve by reducing lead time and increasing quality and productivity. It starts from the belief that production methods can always be improved. The following methods were used to reach these goals. As noted above, a new order for the company was considered for this case study.

6 Improvement

6.1 Reducing production lead time

From the value stream map (Figure 4) and current cycle time graph (Figure 5) it can be concluded that company has the potential to reduce the lead time greatly. Figure 7 represents all the methods which could be useful for this purpose. The cycle time at each workstation is measured and documented as shown in Table 3. One of the methods applied is to collect all three work stations together in the order shown in Figure 8.

Figure 7 Schematic diagram for lead time reduction (see online version for colours)



Source: Sahoo et al. (2008)

Figure 8 New cell designed for production line (U-shape) (see online version for colours)

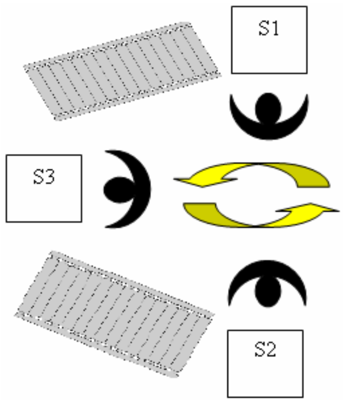
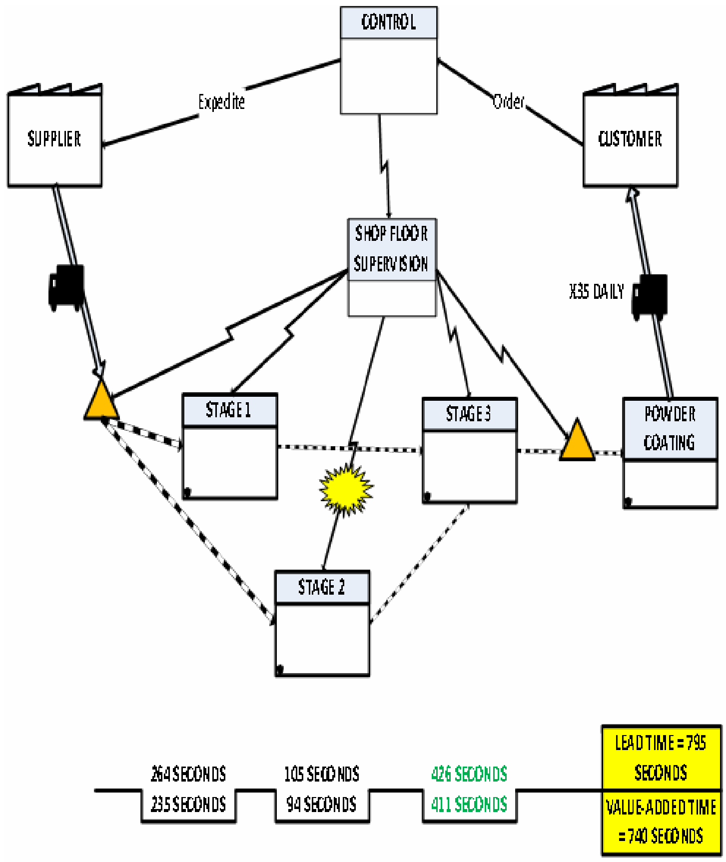


Figure 9 future state map (see online version for colours)



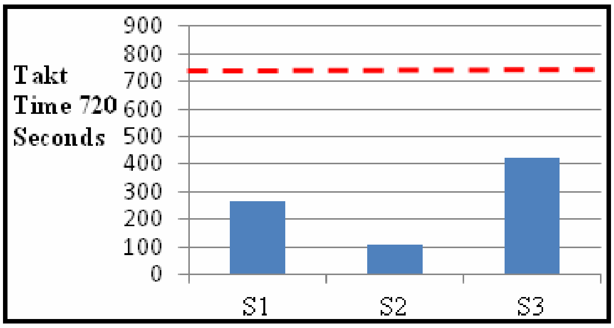
Abdulmalek and Rajgopal (2007) recommend cellular manufacturing as a useful method to reduce lead time and waste. Because the workers in the shop floor are multi-skilled they can easily support each other; the worker in station 2 would be able to support and be involved in the production process in stations 1 and 3. A future state map (future VSM) has been drawn (Figure 9) by considering the new cell design in Figure 8. It is assumed that the worker in work station 2 would finish every day in less than two hours and thus has six hours to cooperate with the worker in stations 1 and 3. Additionally, connecting the cells by conveyors belt reduced the transferring parts significantly.

Table 3 indicates the new results to be obtained from the future state map. It is found that the lead time would be reduced to 13.25 minutes (795 seconds). Figure 10 illustrates the improvement in cycle time in each workstation. It would mean that the order could be completed 41.4% faster than with the previous state. Then the company would be able to start the next order sooner and significant savings in labour costs would be achieved. Furthermore, the inventory load time is reduced significantly.

Table 3 Improved VSM analysis report

Station	*Activity*	*Time in seconds*	*Value-added?*	*Cycle time in seconds*
S1	Raw material initial preparation	29	No	264
	Welding	163	Yes	
	Polishing	70	Yes	
	Push directly to the station three	2	No	
S2	Raw material initial preparation	9	No	105
	Welding	94	Yes	
	Push directly to the station three	2	No	
S3	Reload from inventory and prepare	Removed	No	426
	Welding rails	130	Yes	
	Polishing and welding inside rails	210	Yes	
	Sheet preparation	13	Yes	
	Welding plate	71	Yes	
	Send to inventory	2	No	
Total time			795 seconds	

Figure 10 Improved cycle times (see online version for colours)



Moreover, based on company quality policy, each worker is responsible for product quality. Workers can communicate together more easily through the redesigned cell and it can have a positive effect on teamwork, problem solving, process improvement, and product quality in particular.

6.2 Kaizen team (quality circles)

The philosophy of continuous improvement encourages workers on the shop floor to carry out their tasks slightly better every day. To achieve that and target the miscellaneous, dispatch and fabrication errors which appeared in Figure 8, the Kaizen team of involved workers formed under the leadership of the shop floor supervisor to recognise, analyse and solve work-related problems. The results were real-time with implementation taking place within one month. Most of the successes of the Kaizen team were due to the fact that the system encourages many small-scale suggestions which were cheap and quick to implement, though the overall effects were considerable. Afterwards, the team presented their solutions to the shop floor supervisor in order to progress the performance of the shop floor. The impressive outcome of quality circle on the shop floor were reducing fabrication errors in 73.8%, enhanced quality, increased employee motivation and reduced the downtime of machines and equipments.

6.3 5S

The 5S visual workplace provides a work environment which is clean, well organised and efficient. It will mark with a rapid and visible achievement for the company whilst preparing its workforce for other advanced efforts to improve. In other ways, 5S gives visible and motivating results. Therefore, it is the first step in the implementation of lean manufacturing, total productive maintenance and Kaizen (Monden, 1993; Skaggs, 2010). The dramatic benefit of 5S was that workers made the new production line cleaned to reveal potential problems. Moreover, 5S reduced the amount of time wasted looking for misplaced equipment and materials.

It should be noted that application of Kaizen and 5S in parallel at this case study brought the maximum efficiency and productivity. There were not only immediate improvements in the production process but also lists of the improvement opportunities developed by the team after the Kaizen and 5S.

7 Conclusions

This research brings evidences of genuine benefits from world class manufacturing firms by focusing on the improvement of a production process through the new production line by making a firm connection between operational objectives and manufacturing system redesign goals and objectives. The research began by auditing the shop floor, detail by detail, to identify problems and recognise any waste that might appear during the production process. Then, it started to redesign a new cell by eliminating non-value-added activities and reducing the lead time through VSM to identify improvement points. Additionally, the Kaizen and 5S methods were applied as easily understandable, highly reliable and effective tools for improving product quality and reducing scrap. After six months of study and assessment of results, including primary and secondary data, it was confirmed that the application of lean production methods helped significantly to enhance the value-added activities in the production line, whilst reducing waste and improving quality. The results from the future VSM explain that the redesigned cell has the potential to reduce cycle time by more than 50% and lead time by 41.4%, while removing unnecessary non-value-added activities. Moreover, the author has given special attention to quality issues as an integral part of continuous improvement while the fabrication errors reduced in 73.8%. The major benefits of 5S and Kaizen will not accrue except by instilling suitable organisational values and setting up a reliable organisation structure, employee empowerment systems and long-term plans for continuous improvement. In fact, tangible improvements in productivity and quality have been achieved after implementing Kaizen and 5S in the shop floor. In conclusion, close collaboration between the company management and the shop floor personnel in the long run underlies the complete accomplishment of the application of lean philosophy. To conclude, it is hoped that this research will be found worth the attention of practitioners in the manufacturing world.

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