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A Systematic Process Improvement Model from Manufacturing Perspective

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***Abstract*— The objective of this study is to present a series steps of development methodology for developing a process improvement model from manufacturing perspective systematically. The proposed development methodology emphasized on building the process improvement model by incorporating all related criteria with suitable tools that can be used in selecting the improvement solution systematically. In this paper, a process improvement model is developed by following the proposed methodology. The model is then used to prioritize the problem scope and select the solutions from various options. To test the application of the development methodology, the three-phase model is validated by carrying out a line improvement project in a case company. The case study results show that the model provides a systematic approach in identifying the solutions that can lead to the desired performance improvement. Feedback from the case study verifies the robustness of the developed model. Moreover, the verification of the model also validates the development methodology of the model itself. As can be seen from the results, the methodology for developing the process improvement model has been successfully implemented.**

Index Terms—**Decision analysis, Development methodology, Process improvement, Process improvement model, Production problem,**

I. INTRODUCTION

Business growth is one of the important reasons for assessing process improvement, which begins in the production department. In today's business environments, a company must constantly evaluate its operational processes and continuously practice process improvement in the production floor in order to survive and grow amidst a competitive market. Process improvement in the production line entails not only the application of measures to improve the process itself but also the total situation, including other aspects such as products, equipment and material, and others. The continuous implementation of process improvement allows companies to proactively improve production quality, reduce manufacturing waste, and increase customer satisfaction. However, the implementation of the improvement solutions may fail to deliver the desired results even though the proper procedure is followed. This can be due to the lack of understanding and the inability to systematically perform process improvement to prioritize the optimum solutions [1]. There are many improvement approaches being introduced and applied in different environments. Problems with varied contexts and scopes must be solved using the approaches deemed suitable for each context. Companies can utilize various types of improvement approaches simultaneously, but the industrial practitioners must learn and master these approaches, such as Business Process Redesign [2], Business Process Reengineering (BPR) [3], Six Sigma [4], and others, in support of process improvement. However, combining these approaches lead to confusion, especially when the intended users are unable to integrate the concepts and methodology of each approach. Furthermore, when combining different approaches, users are unable to focus on and gain mastery of one approach [5]. Therefore, a simple, structured model-based and industry-relevant concept of selecting an improvement solution is needed. During the process improvement, the desired objectives are determined by identifying the problems and then translating them into improvement actions. The ability to generate a set of alternatives is an important part of problem solving and decision making. To ensure the successful deployment of the objectives, a range of feasible alternatives must be identified before the final selection decision is made. The improvement solution could be in the form of a wide range of improvement programs, such as just in time (JIT), poka yoka and Six Sigma, or specific decisions such as redesigning the operational process steps, providing frequent training to operators, and so on. Identification of the accurate solution at the initial stage of the improvement project can significantly lead to rapid improvement in a short period of time. Yet, there are difficulties involved in listing the possible solutions, and these occur when the problems cannot be identified in a single work place. Consequently, Smadi claimed that it may be difficult to correctly solve this problem due to the lack of a clear understanding and vision of the problem focus [6]. The findings of the current work highlight the issues surrounding process improvement and help identify the gaps in literature. At present, there is a lack of guidance or methodology to develop the general, systematic, and structured process improvement models or frameworks that can be used in any production industry. At the same time, there is a lack of related work regarding the selection of improvement solutions and links with improvement objectives. To solve the gaps in literature, a series of methodology development stages is presented in this paper. The structure of this paper is organized into sections. In Section 2, we review the existing process improvement model found in literature. The methodology of developing the new model is presented in Section 3. The development of the three-phase model is also presented in Section 3, and is then applied and verified in a

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practical case study in Section 4. Section 5 discusses the results of the study. Finally, Section 6 gives the conclusion.

II. DEVELOPMENT METHODOLOGY

This section presents the development of the model methodology to be used for selecting and prioritizing the improvement solutions to be implemented in this study. The methodology is developed and then used in order to establish a new comprehensive model that fulfills the requirements. The main stages used are illustrated in Figure 1. Three stages are identified. First, each selected model or framework is reviewed and categorized to identify the decision criteria. Second, the decision criteria are incorporated using the structured tools. Finally, the structure and content of the model are organized and formed. By following the methodology, a model consisting of a decision making tool that assists the selection process is developed. Once the model is developed, it is tested in the case study company.

Fig. 1: Process of developing the conceptual model

A. Identifying the decision criteria

In first stage, some process improvement approaches are selected and reviewed in order to identify the key criteria for the selection model. Zellner [7] evaluated the quality of the selected approaches in terms of their ability to completely support the improvement goal. Therefore, the approaches selected in this study must fully accomplish at least two out of four criteria that involving activities, techniques, roles, results, and information model. Among the selected approaches shown in Table I, the key criteria for process improvement are identified as follows: defining the problem areas, analyzing the problem areas, and implementing the solutions. These are the requirements of developing the preliminary stage of the selection model. Therefore, the focus areas of the model feature a process that spans from defining production problem up until the selection of the solution.

B. Incorporating the decision criteria

Once the criteria are determined, the next step is to further investigate and clarify the criteria through structured tools in order to develop a comprehensive selection model. A major influence during the selection is the decision making method employed. The success of the improvement project depends on the successful adoption of the tools and techniques in the frameworks and models. With so many improvement solutions underway, the decision model must be able to determine which of these should be prioritized. Ideally, the improvement team needs a selection model that can enable the members to draw on their knowledge and experiences. The selection model should provide the appropriate level of functionality and detail, must be easy to use, and must be able to undertake sequential decision making throughout the entire process—from identifying relevant criteria to evaluating decisions by linking them. A few suitable engineering tools, such as quality function deployment (QFD), fishbone diagram and Pareto diagrams, are useful in ensuring the selected solution is in accordance with the goals and is within the project scope [8]. Literature reveals that the proposed QFD approach is easy to understand, can be easily applied in non-product application, and is suitable for improvement projects that are not widely explored. QFD provides the mechanism for integrating the important factors or attributes and link those to the stages of solving the improvement problem. The interdependence among the factors or attributes can be evaluated using QFD approaches[9, 10]. These are supported by Marriott et al. [11] who reported that QFD can handle the prioritization of improvement initiatives. In addition, the decision criteria must be generated and linked for evaluating and analyzing the alternatives, as discussed in the problem statement presented in Section 1. Without utilizing systematic tools, too much time may be spent analyzing the existing process. In certain cases, the project with a very broad scope cannot be completed within the stipulated time frame. QFD is widely used as a strategic decision making tool, as reported by Killen et al. [12] and Sofyalioglu [13]. In their respective works, they used QFD to systematically target opportunities and identify innovative strategies, which should be prioritized, by linking all the criteria considered. For instance, Barad and Gien [14] adopted QFD to apply a contingency-oriented approach to the priorities by connecting the improvement actions of a company with its strategic and operational improvement needs. Thus, in the current study, the QFD is used as a decision tool to link the generation specific criteria, prioritization, and measurable technical requirements in order to improve problems in the production floor. The three specific criteria determined in stage 1 can then integrated using QFD approaches.

C. Form Structure and Content

By combining all the elements that had been discussed, a new three-phase model have been developed (Fig. 2). The proposed model of solution selection adopts the QFD concept, and is created by combing the paramount parts and improving the limitation of the reviewed process improvement approaches. It fulfills the framework design requirements and gaps for selection along process improvement. Three-phase model links the decision criteria quantitatively in order to select the appropriate improvement solutions. The three-phase model is a simple yet logical guidance of improvement. Here, the three-phase model is used as a guideline to address decisions on selecting the appropriate solution for production floor problems. The model mainly directs the improvement efforts to the most problematic area in the production line in terms of production waste generated.

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Table I Mapping the selected process improvement approaches with common methodology stage (*Sorted out from Zellner [7])

Author(s)*	Approach*	Methodology stages								
Lee and Chuah [15]	A SUPER methodology for BPI	Select the process (I)	understand the process (I)	proceed with the process measurement (II)	execute the process improvement (III)	review the improved process				
McAdam [16]	An integrated business improvement methodology	Identify the critical process for improvement (I)	Analyze the current process(II)	Improve the process (III)	Implement the improved process (III)					
Adesola and Baines [17]	MIPI methodology	Understand business needs (I)	Understand the process (I)	Model and analyze process (II)	Redesign process (III)	Implement the new process (III)	Assess new process and methodology	Review new processes		
Povey [18]	Best practice BPI methodology	Create a vision (I)	Create the conditions for successful change (I)	Develop strategies (I) and (II)	Assess the need for and type of change (I) and (II)	Experiment continuously with pilot studies and demonstrations (III)	Plan and implement changes (III)	Train staff in the new processes	Continuous improvement	Sustain the momentum
Varghese [19]	Strategy for launching meaningful BPI	Data collection(I)	Targeting process (I)	Ongoing process management (II)	Managing and improving the process (III)					
Common stages of improvement methodology		Define problem area (I)	Analyze the causes of the problems (II)	Implement solutions (III)						

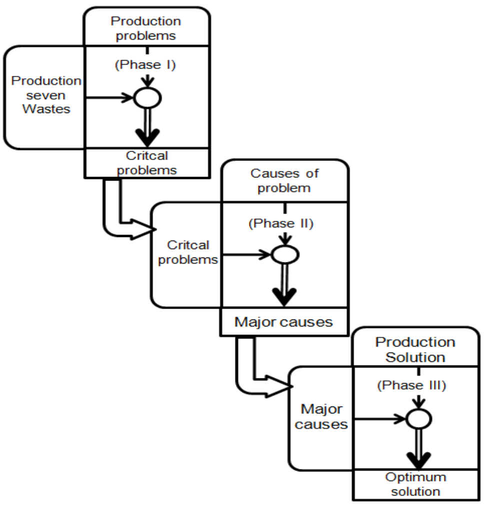

Fig. 2: The three-phase model

The three-phase model provides sequential phases for problem identification, root cause analysis, and improvement solution selection. First, the production problem is defined through an investigation of the real situation. Then, several criteria, such as the root causes of production problems, are determined in order to understand the situations that give rise to production problems. Based on the root causes, the list of improvement solutions is generated, and the optimum solution among these is selected for implementation. Hence, the three-phase model can guide the practitioners in selecting the accurate solution for achieving the desired results.

III. CASE STUDY VALIDATION

The case study approach is chosen in this research to validate the developed model. A case study company is selected. This company shall be the test case for the adoption and validation of the three-phase model. The selected company, Company A manufactures and assembles electrical and electronic parts for radios and audio speakers, telecommunication products, and others. Given the continued increase in customer demand, Company A decides to execute the lean transformation projects in the production line. Through the line improvement project, Company A aims to improve its competitive edge by optimizing production performance of high runner product family. In this case, we propose a simple but efficient model for selecting the optimum solution in the improvement project, which is the three-phase model. The phase-by-phase of three-phase model

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is used as a guideline for improving the specific line for Company A.

From the preliminary investigation, some production problems have been identified and highlighted below.

- **Lengthy material handling path**
  This refers to the number of operators needed to move to and from the production line to get parts from previous processes, i.e., from one workplace to the next. This is due to the limited number of machines, particularly the printing machine, which has to be shared by several parts of the production line, to complete the printing process.
- **Low utilization of operator**
  This situation occurs when the operators perform a simple task that can be completed in a much shorter time compared with the task in the previous workstation. This leads to an unbalanced workload and idling of the personnel (i.e., operators). The workload between processes is also unbalanced, that is, when some of the processes only require a few sub steps, waiting for the next part to arrive leads to idling.
- **Accumulation of inventory of parts in one workplace**
  This refers to the event wherein the inventory for the sub parts is accumulated in each workplace, thus leading to an overcrowded workplace. Moreover, the inventory that pertains to the semi-finished product flows along the process line through the conveyor. For example, a batch of products is accumulated and then proceeds to the printing process far down the flow line.
- **Unbalanced job assignments for some process steps**
  This refers to the event wherein similar jobs are assigned in the non-bottleneck process step, resulting in jobs that are completed faster while waiting for the materials to arrive from the previous process step. Hence, the idling time for operators who perform the simple tasks is increased. In some cases, the operators divide the tasks in the parallel process by themselves. For example, the first operator keeps the sticker for the second operator instead of applying the sticker to the product. Those two tasks can actually be done by just one operator.

The production problems mentioned above, such as lengthy waiting times or idling, are considered as production wastes. Hence, the main objective of the line improvement project is to improve productivity by reducing the lengthy flow time of the production line. Three-phase model are constructed and the results are analyzed. From the output of Phase I, six wastes related to the production problems have been identified. Other critical problems include lengthy material handling path, followed by unbalanced job assignment (Fig. 3). These problems are thus prioritized and transferred to Phase II.

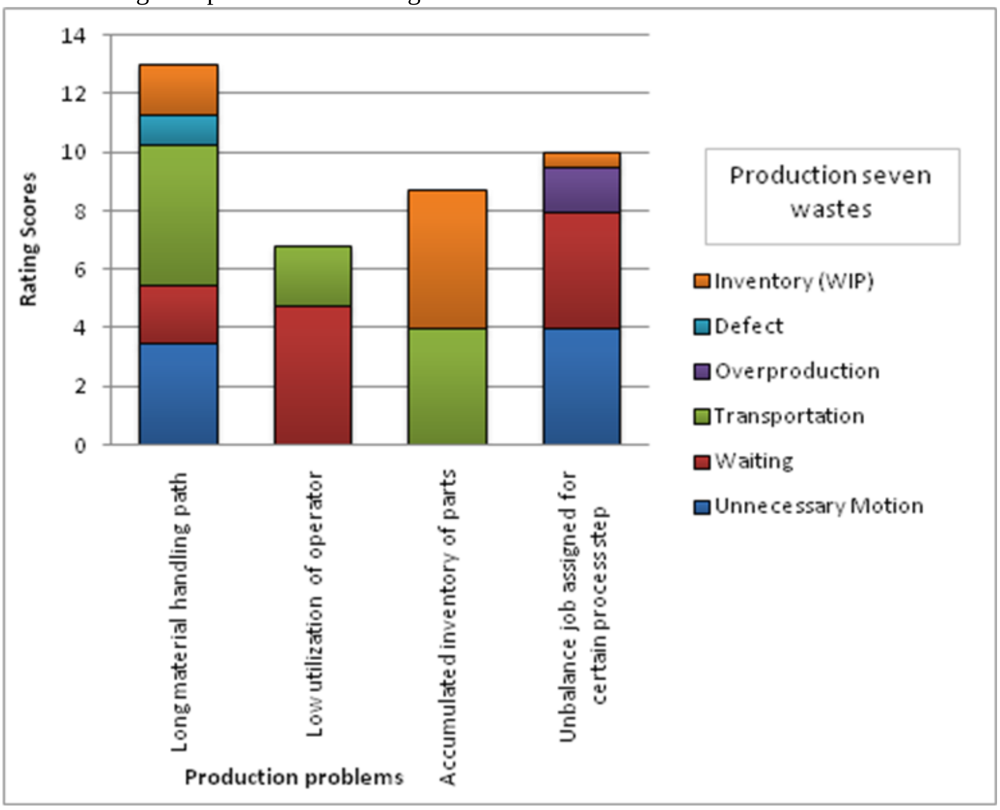

Fig. 3: Results of the analysis of Phase I

In Phase II, the root cause analysis is carried out. As shown in Fig. 4, delaying the material is the most important cause of the critical problems. This is followed by the unstructured process sequence that caused unnecessary movement and idling that occurred in the production line. Eleven of all possible causes are selected as the critical causes and then transferred to Phase III where the solutions are generated.

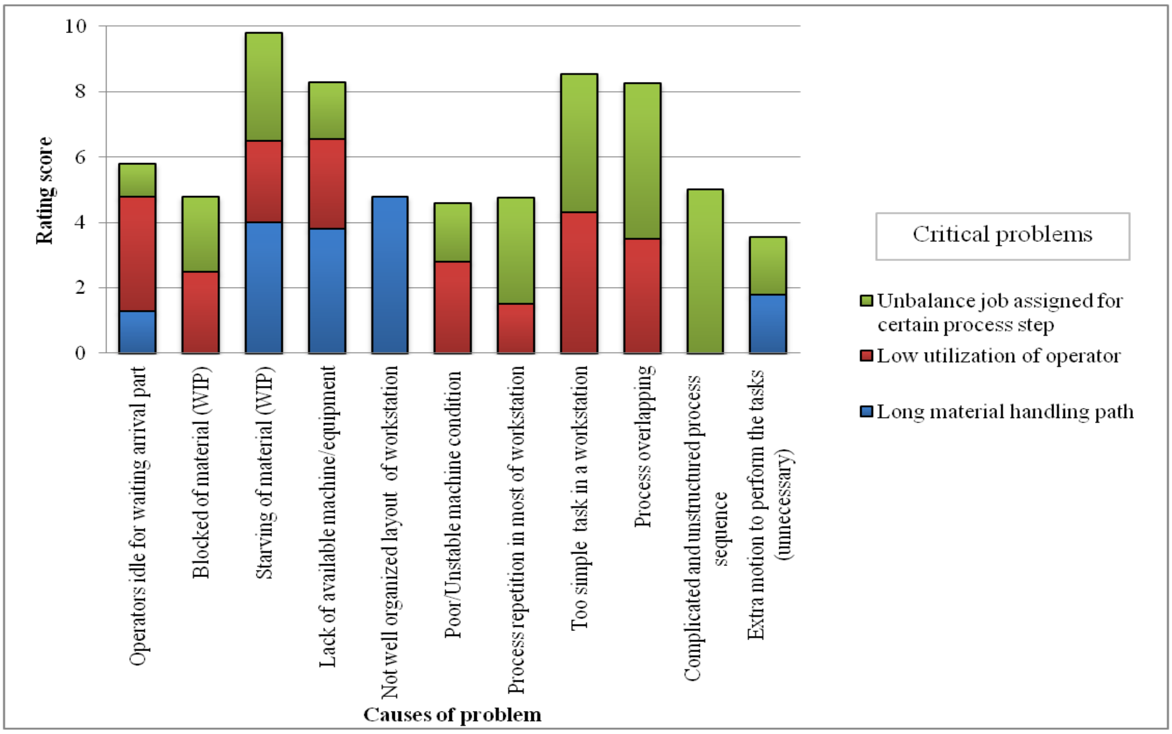

Fig. 4: Results of the analysis of Phase II

From the output of Phase III, the top three prioritized improvement solutions are selected. The solution with the highest score is redesigning the process tasks (Fig. 5), followed by reallocating the process workplace to reduce the handling material path. These prioritized solutions are then pilot-tested before any actual implementation is initiated.

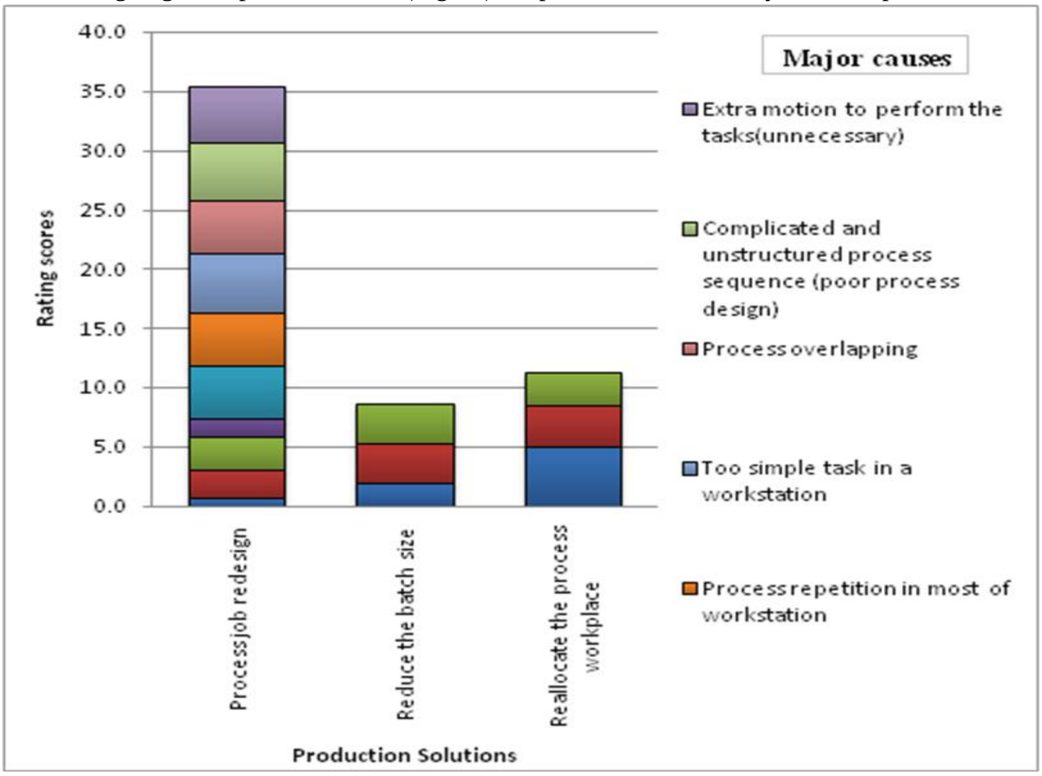

Fig. 5: Results of the analysis of Phase III

The improved results are analyzed and presented in Table II. The results show that the project goal has been realized, as demonstrated by the 11.03% reduction in the production flow time, and 20% improvement in operator number in the overall line. These results prove the robustness of the three-phase model as well as validate the acceptability and practicality of the developed model for actual industrial applications.

Table II Comparison results before and after improvement

Measure	Improvement		Improvement percentage (%)
	Before	After	
Production flow time(s)	151.1	134.4	11.03
Number of operator required in the line	15	12	20.00

IV. DISCUSSION

The application of the three relationship matrixes in each phase of the developed model is correlated to the decision-making from problem identification to the selection of the effective alternatives for the improvement project. Prioritization is also conducted in solving the production problems. In this process, the problems, root causes, and improvement solutions are prioritized in relation to the specific scope of critical problem areas. The phases of the developed model are clearly defined to make it easy to adapt and use. The phases incorporate improvement tools in each of the developed IPS model's stages. Each phase follows the four general selection steps, namely, brainstorming and agreement of the selected criteria, weighting, rating and ranking, and result analysis. Adopting the decision tools helps prioritize and associate the decision criteria along with the selection process. Otherwise, the teams are unable to link their selected improvement solutions to their goals. The relationship matrices are generated as decision tools, by which the generation of specific criteria, prioritization, and measurable technical criteria can be quantitatively linked to resolve production problems. Interdependence among the criteria in support of the decision-making is also evaluated using the relationship matrices. The three-phase model can generate accurate decisions and reach the target output, i.e., the best solution for the improvement project.

V. CONCLUSION

In conclusion, the methodology of developing the three-phase model is suitable for designing and developing the model itself. The three-phase model has been developed based on the methodology shown in Figure 1. As shown by the results, the model can provide a systematic and effective way of quantifying the decision criteria and link the stages to one another. This model can assist engineers in selecting the solution that solves the prioritized problems, which must be implemented by the management. The structure of the decision-making process used in this model can be effectively tailored to the selection of process improvement in a specific company. It is recommended that future works implement solutions that are simulated within actual conditions and then monitor the performance results closely. Furthermore, the revised model must be verified and validated again using another case study for further refinement.

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