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House of Improvement Model to Enhance Prioritisation of Solutions in Decision Making: a Case Study

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ABSTRACT

The decision making on selection of improvement solutions was one of the obstacles hampering the success of process improvement. This paper presents the House of Improvement (HOI) model as a guideline to link decision criteria for the prioritisation of improvement solutions. Three phases in the HOI are applied to facilitate selection and to ensure that suitable and value-added solutions are chosen. Each phase includes procedures for identifying, evaluating, and analysing the elements by establishing a relationship matrix. The reliability of each relationship matrix will be tested in order to proceed to the next phase. The adopted matrices in the HOI serve as decision-making tools for analysing potential and critical problems in the production line, evaluating possible effects of the critical problems, and innovating on the necessary actions for the solution. Using a real-life case study, this paper demonstrates the applicability and suitability of the HOI model in providing prioritised solutions for production problems experienced by small and medium enterprises.

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1. INTRODUCTION

Industries, especially manufacturing, must respond quickly and efficiently to changing production requirements to be more effective and responsive to customers' needs and achieve market competitiveness. Responsiveness allows industries to undertake continuous refinement and improvement of their operational processes to reduce waste [1]. Process improvement is a series of actions undertaken by firms, such as regular review of existing operational processes, identification of performance problems, analysis of problems, selection of best solutions and implementation of improvements in a systematic manner. In fact, the process of selecting the solution for problems from a set of alternatives is critical in determining the failure or success of process improvement. Along the improvement project, the ability to prioritize effectively during decision-making is important to specify the focus and narrow down the scope of the improvement process stage. By incorporating the prioritization issue in process improvement, the organization is able to give less attention to problems that are unimportant to be solved and devotes more time to those areas that are critical and important to be solved. Many process improvement methodologies or models were developed to assist practitioners in process improvement [2, 3]. However, prioritisation selection in focused areas and improvement actions are not considered in those developed methodologies. When the areas considered consist of more than one problem area, the organizations are rendered, incapable of solving all problems at once, when given a shorter timeframe. Therefore, prioritisation is required to obtain the proper direction of process improvement in shorter time. Varghese [4] and Siha and Saad [5] developed process improvement models to determine the appropriate areas to be prioritised. However, the solutions are not ranked according to the prioritised areas to be solved. When numerous solutions are generated at the same time, solution prioritisation becomes one of the greatest obstacles to the success of process improvement projects. Therefore, the prioritization of improvement solution using the right and suitable developed model is

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of utmost importance. Incorrect solutions prioritization may be detrimental to the company's performance as a whole. Essential decision-making aspects and criteria must be considered and linked to identify and prioritize the correct alternative solution [6]. One of the possible barriers is the improper relation of selecting the solutions criteria, causing failure to the process improvement projects due to inaccuracy of decision making.Certain organizations may be unable to link their selected solutions to their improvement project goals, though these are specified correctly [7]. Therefore, adopting suitable quantitative linkage criteria, from identifying opportunities to select the solutions is critical to the success of the improvement project.Over the years, researchers have applied various quantitative approaches to connect the decision criteria in non-process improvement areas, such as analytic hierarchy process or AHP [8-10], analytic network process or ANP [11, 12] and quality functional deployment or QFD [13, 14]. These researchers used quantitative techniques to link and prioritise the related requirements and decision criteria in a wide range of applications. QFD provides an excellent mechanism for integrating the important concepts and linking major steps, as well as for offering a rigorous methodology for identifying related priorities. This approach was applied to develop the order of decision criteria [15]. Moreover, QFD is observed to be easy to apprehend, being suitable for non-product application [16, 17]. Barad and Gien[18]utilised QFD to determine improvement priorities, and proved that it is capable of linking the improvement priorities of an enterprise to its manufacturing strategies in an innovative manner.However, their work focused on action selection rather than the process of prioritizing improvement opportunities. As stated, the prioritization issue and criteria linkage were vital in the process improvement in order to make an accurate decision. Current studies lack prioritization issues and quantitative linkage of decision criteria along the process improvement from improvement opportunity identification until the improvement solution selection in production line. Without linkages between criteria, the prioritization process may cause bias result in the solution selection in the final stage of process improvement. Therefore, a study is needed for emphasizing on the process of preliminary prioritization of problems until the possible solutions being examined by decision makers in organization and their linkage criteria between the decision making process. The main objective of paper focuses on developing a structured model from determining production problem priorities to select the solutions priorities in process improvement. The proposed model utilized QFD, and the adoption of this tool brings together a linkage between full ranges of decision criteria to facilitate a more robust decision-making process. The QFD makes the decision criteria interchangeable and compatible to different improvement process activities' uniqueness for different improvement targets. Hence, the model is feasible to address different types of production problems relevant to the manufacturing wastes. The HOI model leads the organization to select the solutions more feasible based on the prioritized problems. The remainder of this paper is organized as follows: in Section 2, amodel, namely House of Improvement (HOI) is described with a proposed set of steps ranging from problem identification to implementation. In Section 3, the developed selection model is applied in the manufacturing organization and the results are discussed. Subsequently, discussion is presented in Section 4. Finally, a summary of the findings is presented and future research issues are suggested in Section 5.

2. HOUSE OF IMPROVEMENT (HOI) MODEL

In this study, the QFD concept is deployed in a non-product application. In this paper, a modified QFD tool is adopted specifically for solution prioritisation in process improvement. HOI is the proposed model for solution prioritisation. The nature of decision-making in selecting the improvement solution differs from the product development process, which is the original purpose of QFD. Such differences lie in the types of information used, generally involving personnel, potential impact, and decision output upon company performance and components of matrix in HOI. This model serves as a guideline for addressing decisions on selecting the solutions for production problems, and it begins with the identification of problems. The model mainly directs improvement efforts to the most problematic area in the production line, particularly in terms of production waste. The HOI model is divided into three sections, which are preliminary, professional judgment, and evaluation sections as shown in Figure 1. In the preliminary section, the team will be formed by the expert personal and the weighting of the seven wastes will be determined using pair wise comparison matrix.

In the professional judgment section, the concatenated matrix in HOI model provides main sequential phases for problem identification, root cause analysis, and improvement solution selection by linking relationship matrices. Lastly, the reliability of the relationship score will be tested for all phases of matrix in the evaluation section. The next phase can proceed only when the scoring data is reliable. Similar steps evaluates the relationship between the criteria in the three phases of the relationship matrix.The differences lie in the types of criteria used as well as in the decision-making output.The three sections of the HOI model are described in the following sections.

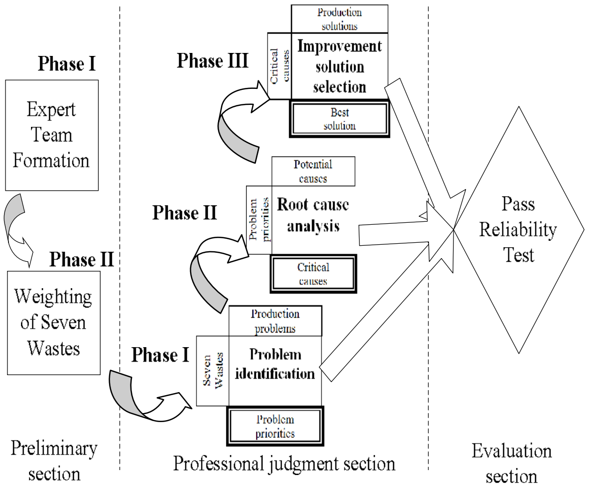

Figure 1. Three section HOI model

TABLE 1. Fundamental scale of importance level of DOTWIMP [8]

Importance	Definition	Explanation
1	Equal importance for elimination	The levels of importance of eliminating the two wastes are equal
3	Weak importance of eliminating one wastecompared with another	Based on experience and judgment,the level of importance of eliminating one waste is slightly higher than that of another
5	Essential or strong importance for elimination	Based on experience and judgment,the level of importance of eliminating one waste is considerably higher than that of another
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of theabove non-zero values	If waste i is assigned one of the above non-zero values When compared with waste j, then j obtains the reciprocal value when compared with i.	

2. 1. Preliminary Section In the first section, there are two phases involved before further analysis using relationship matrix:

2. 1. 1. Phase I: Selection of Expert in Improvement Team Formation The improvement team is responsible for coordinating the progress of the development process. During the process improvement, an output of work from a team is better than an individual because of the increased creativity and capability required for achieving improvement. The team must be active in identifying problems and authorised to make decisions in terms of selecting the problem and solution that will be implemented. Therefore, the experts who have adequate background and experience in the company's operation and production department, will be the options. Hokstad et al. [19] claimed that the quality of expert in terms of their assessment and judgment is more important than the quantity. Therefore, the selections are usually based on the number of experts available in the focused study. Perhaps, too many experts are difficult to contribute in the same team. Hence, it is suggested not to select more than two members from management level groups and no more than four technical expert groups in a team.

2. 1. 2. Phase II: Weighting of Seven Wastes This step determines the weighting of non-value added manufacturing wastes through management of the production department. Non-value added wastes are categorised into the following seven types of wastes (Ohno, [20]: defects, overproduction, transportation, waiting, inventory, motion, and over-processing (DOTWIMP). Pair wise comparison matrix is the tool used to determine and assign qualitatively importance level for the elimination of wastes based on the fundamental scale in Table 1 [8].

Based on the rating value, each waste is characterised by a quantitative weight. The higher the weighting of wastes, the higher the important level of those wastes to be eliminated. In other words, high weight wastes are considered the critical wastes, which has the priority to be solved and eliminated. The experts that were selected from the company in Step 1 determine the rating. The rating is based on the experts' experience and judgment. Then, each of the matrix consistency, suggested by Saaty [8] will be examined for formulating and identifying whether the judgment are consistent. If the consistency ratio (CR) is above 0.1, the experts who made the judgment should compose a new judgment in rating the DOTWIMP wastes right through the CR which is below 0.1. Once the weighting of wastes is concluded, the process will advance to the stage that is professional judgment section for problem identification.

2. 2. Professional Judgment Section In this section as illustrated in Figure 1, there are three phases to ensue in order to obtain the best solutions that are problem identification, root cause analysis, and improvement solution selection. Each of these phases require to acquire the opinion of the expert who had been selected in the preliminary section. In this study, the expert team member who was selected from preliminary section need to answer questionnaires in two cycles. The first cycle is to list out the specific criteria (e.g. production problems, causes of problem and solutions) at each phase. Then, a summary should be completed from the result of previous cycle and will be the input for the next cycle. In the second cycle, the questionnaires will be in the form of relationship matrix. At the same time, the experts are encouraged to revise their results from the previous cycle as the feedback and will be looped until it is completed. The reliability of the results will be tested before progressing to next phase. The average scores among the expert teams in the second cycle will be used as the result for analysis.

2. 2. 1. Phase I- Problem Identification In the first phase of HOI, the main task is to identify the problem priorities by determining the relationship between the seven wastes (vertical criteria) and production problems (horizontal criteria). Their relationships are identified using the relationship matrix (Figure 2). The outputs of Phase I represent the production problem priorities, which will serve as input in Phase II. There are two steps to be followed to complete Phase I:

Step 1.1: Identification of production problems

This step involves rigorously scanning and screening the environment of the assigned production line. Preliminary information is gathered to determine the current situation level, such as daily production rate, cycle time, layout distance, and number of operators. This can be obtained from company documentations, such as review of company report as well as unstructured and structured interviews with workers in the production line. Inputs from managers will help to define the problem areas and the factors that trigger these. Data type and suitable collection tools depend on the specific cases. Collected data can be presented in figures or quantitative form. Brainstorming is conducted to gather the production problems occurring in particular areas. During the brainstorming session, team members must agree on the criteria items, such as the production problems that they wish to use for the selection through the relationship matrix.

Step 1.2: Production problem priorities

The interrelationship process identification in Phase I begins once the production problems are determined in Step 1.1. In Step 1.2, production problem priorities are determined by following the proposed procedures presented in Figure 3. In the Procedure 1, a structure of relationship matrix, as shown in Figure 2, is prepared. The seven wastes (Ax), with their weighting calculated in Step1, are listed in the vertical criteria of the relationship matrix. Meanwhile, the sorted production problems (Ay) obtained from Step 1.1 are listed in the horizontal criteria of the relationship matrix.

In the Procedure 2, rating scores (S) are assigned to evaluate the production problems based on the wastes (DOTWIMP). Team members rate the interrelation room of matrix to quantify the relationship between the DOTWIMP and each production problem. A rating or priority scale is set for the input of matrices (Table 2). The variable that considered during rating process are agreed upon in process improvement that being initiated early. Therefore, the variable resources requirement is considered as minor variable, which does not give that much impact to the end of result. In this matrix, the strongest relationship between waste type and the production problem is assigned the maximum value of 5, while relatively weaker relationships between both criteria are accorded a lower value. Zero point is given or left blank to the element pair that has no relationship at all. Rating scores (S_{xy}) are given upon the agreement of each team member.In Procedure 3, the assigned rating value was justified before further analysis. One of the general criteria for evaluating the quality of any measurement procedure is the reliability factor.The measurement of reliability is essential to ensure that the ranking scores value are constant and ample.The data is considered reliable when it is free from errors and repeatable and has an internal consistency.

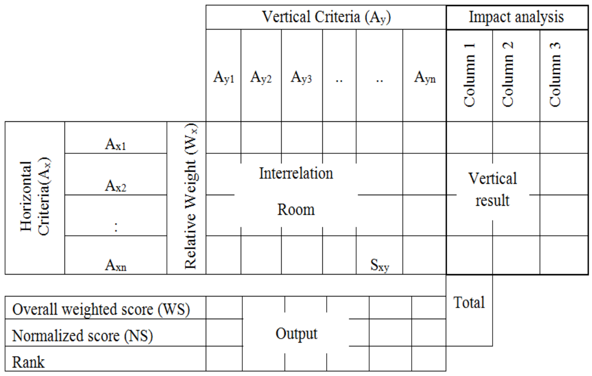

Figure 2. Template of relationship matrix in HOI

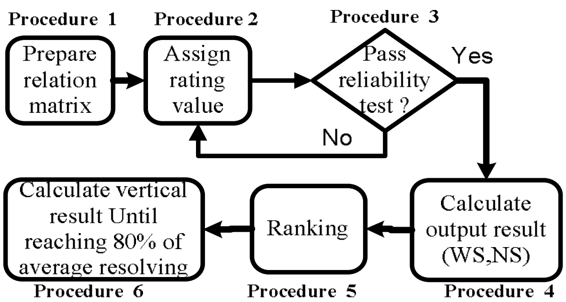

Figure 3. Proposed procedures in the relationship matrix of Phase I

TABLE 2. Rating score of the relationship level

Rating value, S	Level of relationship
5	Very strong
4	Strong
3	Medium
2	Weak
1	Very weak
0	No relation

Using the reliability analysis, the extent to which the criteria in the matrix are related to each other within the expert selections can be determined. The reliability had been tested in term of Cronbach's alpha which was the internal consistency based on the average inter-criteria correlation. As shown in Equation (1), alpha measures true variance of each questionnaire in second cycle over the total variance. The equation was used for calculating the reliability of each phases of matrix. Through the value of the Cronbach Alpha coefficient, the consistency and reliability within experts can be judged. In addition the overall index of the repeatability or consistency of the scale as a whole can be determined.

$$Cronbach\, a = \left(\frac{k}{k-1}\right)\left(1-\frac{\sum_{x=1}^{k} S_x^2}{S_p^2}\right) \quad (1)$$

where$k$= number of criteria in scale; S_x^2 = variance of criteria x and S_p^2 = variance of total score

Generally, a higher value of Cronbach's alpha leads to a higher reliability of the questionnaire. However, the team member's rating in questionnaires that consist of lower range of acceptable Cronbach's alpha should be either re-rated by the team member or excluded for further analysis. The re-rating process will be keep repeated until reaching the acceptable range value. Conversely, the exclusion of the rating value is removing the irregular rating value from that particular team member and not been considered in the analysis of prioritisation process. The matrix is highly reliable when the value of Cronbach's alpha is higher than 0.7. If the value is between 0.35 and 0.7, the reliability of the matrix is acceptable [21]. Once the rating is acceptable, the average rating of the selected experts will be preceded to next procedure.

In the Procedure 4, overall weighted score (WS) and normalized score (NS) for each production problem is calculated similar to the conventional QFD concept [22]. WS for each production problem determined by summing the product of each rating score (S_{xy}) and relative weight (W_x) of seven wastes [Equation (2)]; normalised scores (NS) are then calculated using Equation (3):

$$\text{Overall Weighted Score, (WS)}_{xy} = \sum_{x=1}^{n} (W_x \times S_{xy}) \quad (2)$$

$$\text{Normalized Score, (NS)}_{xy} = \frac{(WS)_{xy}}{\sum (WS)_{xy}} \times 100\,\% \quad (3)$$

where W_x is the relative weight or importance of the xthitem in the vertical criteria (seven wastes); S_{xy} is the rating score of the yth in the horizontal criteria (production problems) to the xth vertical criteria (seven wastes); y is the number of items in the vertical criteria (production problems); and x is the number of items in the horizontal criteria (seven wastes). In Procedure 5, the sequence of preferable production problems is ranked from highest to lowest NS. The top rank of production problem based on the value of NS indicates that it consists of many types of wastes; it is categorised as a critical problem. The high priorities of production problems can be determined based on the ranking result.Then, the vertical result is calculated (Procedure 6) using Equations (4)–(7) for the respective columns (Figure 2). If items in the vertical criteria have higher percentage, it means that the selected items in the horizontal criteria have the stronger and closer relationship with them. If the percentage of a waste type is high, the selected production problems (problem priorities) mostly originate from a specific type of waste.For score weighted waste type, the following equation is used:

$$Column\ 1 = \sum_{y=1}^{n}(W_x \times S_{xy}) \quad (4)$$

For score of waste type based on the problem selected (highlighted), the following equation is used:

$$Column\ 2 = \sum_{y=1}^{n}[W_x \times (S_{xy} of selected item)] \quad (5)$$

For percentage of the problem selected, the following equation is used:

$$Column\ 3 = \frac{Column\ 2}{Column\ 1} \times 100\% \quad (6)$$

$$\text{Average resolving} = \frac{\sum_{y=1}^{n} column\ 3}{n} \quad (7)$$

Based on their ranking, the number of top scoring production problems selected as the problem priorities increased until the average resolving over 80%, which is acceptable. The matrix in Phase I is used in this stage to identify the critical problems; it will be the main concern of the improvement project in Phase II. The priorities of the critical problems will be transferred to Phase II; these will be input together with the NS, serving as the relative weight.

2. 2. 2. Phase II- Root Cause Analysis

Root cause analysis in Phase II is employed to identify the root cause of the problem priorities; the relationship between the prioritised problems and potential causes in the relationship matrix is determined. Using the temple of relationship matrix in Figure 2, the prioritised problems arelisted in vertical criteria, while potential causes arelisted in horizontal criteria. The output of Phase II, which is a critical cause, will be used as input for Phase III. Phase II is divided into two steps:

Step 2.1: Potential cause determination

In Step 2.1, the process of determining the possible causes is performed based on the input generated from Phase I (problem priorities). Experts require inputting their opinion using the fishbone diagrams. The fishbone diagrams are adopted to determine the potential causes of each production problem visually. If three critical problems are obtained from Phase I, three different fishbone diagrams would be constructed in this step. The possible causes for each critical problem in respective fishbone diagram are investigated and classified in terms of operator, machine or equipment, method/flow material, and environment. Then, all potential causes contributing to each critical problem are gathered in one relationship matrix. The same type of potential causes may possibly appear in different fishbone diagram of critical problems. To avoid overlapping, the possible causes similar to various critical problems are combined and listed in the "Possible cause" horizontal criteria of the matrix in Phase II.

Step 2.2: Critical cause priorities
Step 2.2 identifies and sorts possible causes that contribute most to the problem priorities. Another matrix isconstructed in Phase II. The problem priorities from Phase I are placed in the vertical criteria section in Phase II, while the categorised potential causes are listed in the horizontal criteria section. The NS of the production problem from Phase I is used as the relative weight in Phase II. The higher priority of the production problem carries higher weigthing in this place. In other words, the causes of that particular production problem will be having higher prioriy compared to those oflow wieghting problem. Furthermore, it will be affecting the causes' value of NS in anlysis of Phase II.

The relationship between problem priorities and possible causes is determined using similar procedures, as shown in Figure 3. In addition, their relationships are quantified using similar scoring rate of relationship and calculation method in Phase I. If there is one-to one between problem and cause, there will be only one rating value between each other in the interrelation room of matrix horizontally. While a problem depends on multiple causes, there will be respective rating values between each other in the interrelation room of matrix horizontally.

The critical cause priorities are based on the ranking in the matrix. This output can easily identify the major cause of most of the problems. A high score means a high critical level, indicating that more focus is needed. The top priority of causes is considered as critical; these will be used in Phase III. These critical causes will be transferred to Phase III with their NS, and used as phase input. The vertical result is calculated using Equations (4)–(7). Although the name in the column is different, the calculation method is the same as the one used in Phase I. High percentage of prioritised problems indicates that majority of causes have been selected. Therefore, problem priorities have a stronger and closer relationship with the selected causes.

2. 2. 3. Phase III- Improvement Solution Selection
In the last phase, the main task is to select the best solution for improvement based on the relationship between the critical cause and the improvement solution. Using the temple of relationship matrix in Figure 2, the critical cause is listed in vertical criteria, while improvement solution is listed in horizontal criteria. Their relationships are determined in the relationship matrix. The output of Phase III is a list of best solution sequence for trial implementation. Phase III consists of two steps designed to complete the relationship matrix:

Step 3.1: Production solutions formulation
Step 3.1 formulates the production solution to eliminate the causes of problem priorities. The outputs of root cause analysis in Phase II are dimensions for generating many possible improvement solutions. Thus, the planning of improvement solution isconducted through reverse brainstorming [23] among the expert team. Instead of asking, "How do we solve or prevent this problem?" the team leader may ask, "How can cause the problem getting worst?" Reverse production solutions can be easily rectified against the reversed root causes of critical problems. Through discussion, innovative ideas for improvement are created by reversing the production solutions. Analysis and judgment on the solution are conducted to avoid overlapping. Production solutions are designed to achieve the priorities and focus of the improvement project. All production solutions that contribute to the improvement are listed in the horizontal criteria of the relationship matrix in Phase III.

Step 3.2: Best solution selection
In this step, best and accurate solutions are selected after completing the formulation of solution. More than one possible solution may be generated for specific causes. The list of production solutions analysed from the causes is listed in the horizontal criteria. The NS of the critical causes in Phase II is used as relative weight in Phase III. Similar ratings and procedures of calculation used in Phase I are applied as well (Figure 3) to determine their relationships. A high score is assigned if there is a strong relationship between the critical causes and production solutions. The improvement solutions are selected based on the critical causes from Phase II. If the improvement solutions have close relationship with most of the critical causes, that particular solution has the higher chance for being selected as the best solution. Decisions of selection are not based on the cost of the solution or intricate level for implementation. Lastly, the relationships between the selected solutions and the critical causes are calculated using Equations (2)–(7). Although the column name is different, the calculation method remains the same as that used in Phase I. The high percentage of critical cause indicates that most of the selected production solutions can solve the particular cause. Therefore, the priorities of appropriate solutions are illustrated in the relationship matrix to achieve the project goals.

3. VALIDATION OF HOI MODEL IN A REAL-LIFE CASE STUDY

The developed HOI model is applied in a real-life case study. Company A is a manufacturing firm that assembles electrical and electronic parts, radio and audio speaker parts, telecommunication products, and so on. Given its continuous business growth, company A faces the challenge of meeting increased customer demand. Therefore, the management intends to increase the productivity to cope with customer demand for products while maintaining available resources such as operators, machines, and so on.

Company A decides to improve its competitiveness by improving the productivity. This is carried out through a continuous process improvement project. Thus, an improvement project is initiated and specialised team is formed. The team member consists of a manager and various engineers. In company A, production time is the main concern to be considered when it comes to the productivity improvement. Hence, the company attempts to focus on waste reduction relating to the production activities to reduce the production time. The improvement project is performed in one of the manual assembly lines of company A, which assembles a plastic housing for the communication device. The selected assembly line isin charge of producing high runner product that means the demand is high and constant over time. The process of HOI model, as presented in this paper, is utilised to improve the specified assembly line. The outcomes of the verification and validation of the HOI model is discussed in the following sections.

3.1. Phase I-Problem Identification A relationship matrix is constructed in the first phase. The improvement goal of company A is to reduce wastes in the production line to curb cost. Thus, DOTWIMP is used as input in the vertical criteria section. Weighting must be assigned to the input prior to the construction of the relationship matrix in Phase I, which is DOTWIMP in this project, through pair wise comparison. Each type of waste is rated by the selected expert that is the production department manager, staff engineer and two engineers. Each of the matrixes will be tested for consistency. The result of the pair wise comparison in percentage is determined by the average rating of the four experts. All the experts' CR is below 10%, thus their judgment is consistent and this is considered acceptable from the statistical point of view. Once the consistency is confirmed, the average value among the experts is used in the weighting of DOTWIMP in vertical criteria of Phase I.

After analysing the real situation, production problems are discussed during brainstorming. Identified problems are listed in the horizontal criteria (Figure 4). The given score is used to quantify the relationship between the DOTWIMP and each production problem. The higher rating in the relation room indicates astronger relationship between both criteria. For example, in Figure 4, "Idling operator" has a strong relationship with "waiting" of wastes; therefore, a rating of 4.17 is assigned. Overall WS and NS of each production problem are calculated in the matrix to identify the priorities. The highlighted production problems in Figure 4, along with their NS, are carried over to the next phase. As a result, by having the average resolving value of 89%, the top four critical production problem areas are identified and highlighted in Figure 4.

3. 1. Phase II - Root Cause Analysis In Phase II, the priorities of production problem from Phase I is recorded in the vertical criteria of Phase II. Each weighting of production problem in Phase II is obtained from the NS in Phase I. In order to have a better understanding and to solve the critical problem, their root cause need to be analysed before the solutions are determined. The possible root causes are then translated from the production problems using a fishbone diagrams. In the case study, three fishbone diagrams are constructed.

It summarises the results of the brainstorming session on the critical problems. The causes of production problems are factors that support the occurrence of the problem in terms of operator, machine, material, and flow of method. These possible causes are gathered in the horizontal criteria section of the second matrix in the HOI model as shown in Figure 5.

		Production Problems					Impact analysis		
Wastes type	WEIGHT	Uneven distance apart between processes in the line	Idling operators	Overcrowded workstation	Operator left her workstation to replenish part/part holder	Working motion not constant	Score weighted of wastes type	Score of wastes type based on selected problems (highlighted)	% of problem selected
Unnecessary Motion	8.5		1	0.5	0.67	4.17	54	48	89
Waiting	20.8	4	4.17	2.2			216	216	100
Transportation	9.3	4.33	1.5	0.67	3.67		95	60	64
Defect	35.8	1		0.17	0.83	3.17	185	155	84
Overproduction	8.6	3.83	1.33	1.5			57	57	100
Inventory/WIP	7.9	5		1.33	0.33		53	50	95
Over processing	9.0				0.17	1.67	17	15	91
Overall weighted score (WS)		232	121	85.7	73.7	164		Average resolving	89
Normalized score (NS) (%)		34.3	17.9	12.7	10.9	24.3			
Rank		1	4	2	5	3			

Figure 4. HOI Phase I of case study

Starving for material that consists of 13% of NSs is the most critical cause for those critical problems. Unbalanced work flow and work load for operators (12.2%) cause unnecessary waiting wastes. Eleven possible causes are selected and are highlighted in Figure 5, as the critical cause and are transferred to Step 3 of the HOI model to generate solutions.

3. 3. Phase III- Improvement Solution Selection

In the final phase of the HOI selection model, the list of alternative solutions is selected by considering the critical causes. To solve the problem priorities, improvement solutions must be determined for implementation. Determining the major causes of the problems is an important step in identifying the solution.

The critical root causes are the focus of the improvement project areas. The teams involved in this study conducted a reverse brainstorming session to generate the improvement solutions for the focus areas.

For example, instead of asking, “How can the operators' speed performance be improved?” the team leader reversed the critical cause of problem by asking, “How can cause the operators performed slowly?” Each reverse cause was brainstormed to generate reverse solution ideas. Then, reverse solution ideas were reverted and used as the improvement solution for the original causes of the problem. Lastly, solution ideas were judged and evaluated to avoid overlapping. Figure 6 lists the solutions in the horizontal criteria section.

The full matrix of the items considered in the problem section is shown in Figure 6. The solution improvements that have achieved the highest opportunity to solve the particular causes merit a rating point of 5.For instance, by “providing training and guidance frequency,” the causes of “operator working attitude” are solved directly. Therefore, their relationship obtains a rating of 5. By referring to the NS of each solution activity (Figure 6), two actions for improvement are proposed for the pilot run: 1. Re-sequencing process flows 2. Recombining process steps. Based on the vertical criteria result, the critical causes such as the method/flow consists more than 75% of resolving. These critical causes can be solved by recombining and re-sequencing the process flow of the production line. For implementation, the process steps that can be completed within a short time are considered.

The targeted workstation consists of time that is less than 50% of that acquired in the overloaded workstation because of the simple task assigned. Based on the suitability of the production environment, the targeted process step can be either re-sequenced or recombined with the adjacent workstations, or both. Thus, this will reduce idle time of the operators while awaiting the arrival of parts, as well as the time wasted for waiting in the assembly process.

Potential Causes		Uneven distance apart between processes in the line between process	Idling operators	Overcrowded workstation	Working motion not constant	Overall weighted score (WS)	Normalized score (NS) (%)	Rank
	WEIGHT	34.3	17.9	12.7	24.3			
Poor operator	Lack of motivation	3.67	4		3	270	12.1	3
	Lack of training				4.16	101	4.5	12
	Operators infollow SOP			2	4.33	131	5.8	10
	Poor behavior (eg not concentrate on working)		2	2	4.17	163	7.3	6
Poor material	Starving for material	4.5	4.5	4.5		292	13.0	1
	Blocked of WIP	4.17	0.17			146	6.5	8
	Poor design of product		0.33			5.91	0.3	14
Poor machine	Poor design of workstation layout	3	1	1.67		142	6.3	9
	Too slow of conveyor speed	4.33	3.67			214	9.6	5
	Slow equipment operate		2.83	3.67		97.3	4.3	7
Poor method	No updated and too brief description of SOP				3	72.9	3.3	13
	Improper and inaccurate work instruction		0.17	3.17	2.83	112	5.0	11
	Poor job scope design	1.5	4.67	3.67	1.5	218	9.7	4
	Unbalance work flow, work load	3.17	5	4.67	0.67	274	12.2	2
Impact analysis	Score weighted of prioritized problems	835	507	322	575			
	Score of prioritized problems based on the selected causes(highlighted)	835	501	297	296	Average resolving		
	% of cause selected	100	99	92	51	86		

Figure 5. HOI Phase II of case study

Critical Causes	WEIGHT	Provided training and guiding frequently	Reallocate the assembly line	Rescheduling the utilization available equipment	Reconfiguration of conveyor	Recombine the process step	Re-sequence of process flow	*Score weighted critical causes solved by action*	*Score of critical causes solved by action selected (highligh*	*% of resolving*
		Solution improvement								
Operator										
Operators perform slower than standard time	6	4.5	3.3			2.5		61.5	15.0	24.4
Operators idle for waiting arrival part	6	1.0	4.3		1.8	5.0	3.3	91.5	49.5	54.1
Material										
Blocked of material (WIP)	5			3.8	3.3	3.3	3.5	68.8	33.8	49.1
Starving of material (WIP)	5		1.8	3.0	3.3	2.0	2.0	60.0	20.0	33.3
Equipment										
Lack of available machine/equipment	5		3.0	3.8		1.8	4.3	63.8	30.0	47.1
Not well organized layout of workstation	6		4.8	1.5		0.0	2.0	49.5	12.0	24.2
Poor/Unstable machine condition (eg Heatstake machine)	10			1.8				17.5	0.0	0.0
Method/ Flow										
Too simple task in a workstation	5					4.5	1.3	28.8	28.8	100.0
Complicated and unstructured process sequence (poor process design)	10			1.8		3.8	3.0	85.0	67.5	79.4
Extra motion to perform the tasks(unnecessary)	5	0.3		1.0		2.3	4.0	37.5	31.3	83.3
								Total		
Overall weight score		34.3	97.3	101.5	43.0	128.8	130.3	**535.0**		
Normalized score (%)		6.3	18.0	18.8	7.9	23.8	24.1	**98.9**		
Rank		6	4	3	5	2	1			

Figure 6.HOI Phase III of case study

3. 4. Evaluation Section In conducting the reliability test, the Cronbach Alpha is calculated based on the three phases of matrix within the experts' rating. The consistency of the evaluation by the four experts for each criterion can be judged through this testing. The Cronbach's Alpha coefficient of Phase I (0.756) and II (0.783) matrix are higher than 0.7, while Phase II matrix (0.677) is within the acceptable range. From the analysis, it can be concluded that the rating given by the experts are rationally explainable and do not show any significant biases. It means that, by referring to these data, the final outcome will be reliable. In the case study, the application of the HOI model is correlated to the decision-making from the start of problem identification to the selection of the most effective solution for the improvement project. The selected superior improvement solutions obtained by recombining the process steps and re-sequencing the process flows, were considered reliable and the best options on the basis of reliability test which were carried out.

4. DISCUSSION

This work addresses the selection of the most appropriate solutions for process improvement by providing decision making support method. The developed HOI model is guiding the team forward through an easy way or path for getting the accurate decision. The prioritized solutions that had been selected emerge as the optimal solutions, which allow to take effective action on the most critical aspects, while ensuring continuity to the process of organizational improvement undertaken. Furthermore, the prioritized solution will impact positively the production perspective, in term of production time and cost. The selected solution may be able to let the production to be run smoothly.In the case study validation, the HOI model served as a phase-by-phase decision-making tool, starting with the identification of critical problems and the major root causes of such, and ending with best improvement solutions.

Each HOI phase follows the four general selection steps, namely, brainstorming and agreement of the selected criteria, weighting, rating and ranking, and result analysis. The illustrative case study presented should not be regarded as an absolute template for the use of the relationship matrix in HOI. This model was developed and tested primarily in company A. Variations may occur in the selection criteria if this model is applied to other industries. Decision criteria items in each relationship matrix must be customised prior to the adoption of the HOI model based on the organization perspective and applications. Thus, the HOI model has some flexibility characteristic, so it can be applied to organizational processes in general.

5. CONCLUSION

As stated in Section 1.0, lack of prioritizing and decision criteria linkage issue in the process improvement methodology can be solved by adopting the HOI model. Thispaper is focused on presenting the HOI model by associating the crucial aspects of decision-making to achieve a prioritised solution from the potential generated solutions. The HOI model is developed based on the well-known QFD method. This was tested and verified by conducting a real-life case study in the manufacturing industry. This study proves that the HOI model offers significant advantages to the organization by implementing an improvement process. This result is evident in the adoption of systematic procedures embedded in the HOI selection model. Therefore, selecting the right solution in the process improvement project significantly achieves a rapid solution within a short time. In addition, the organization can easily adopt and understand this model due to its systematic procedure in facilitating the selection process. Hence, the organization can select suitable opportunities in process improvement in the future. The future work of this paper can be a case study in more than one industry, such as the service or health care industries, that has a different culture to make comparison in terms of the practicability of the developed model.

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House of Improvement Model to Enhance Prioritisation of Solutions in Decision Making: a Case Study

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چکیده

یکی از موانع پیش روی موفقیت در فرایند بهسازی، تصمیم گیری برای گزینش روش مناسبی باشد .این مقاله، یک مدل مجموعه بهسازی به عنوان راهنمایهایی برای اولویت بندی شاخص های تصمیمگیری گزینه های بهسازی ارائه می دهد . برای این منظور، از سه فاز در مجموعه مدلسازی برای تسهیل انتخاب گزینه مناسب به سازی و راه حل های با ارزش افزوده استفاده می شود . هر فاز شامل شناسایی، ارزیابی و تحلیل المانها از طریقه ساختن یک ماتریس وابستگی آجزا می باشد . میزان اطمینان پذیری هر ماتریس وابستگی به منظور اجرای فاز بعدی امتحان می گردد . ماتریس های اتخاذ شده در مجموعه به سازی به عنوان یک ابزار تصمیم گیری برای تحلیل پتانسیلها و مسائل بحرانی در خطوط تولید، ارزیابی اثرات محتمل و نوآوری به منظور اقدام ضروری برای هر راه حل بکار برده می شود .این مقاله، قابلیت کاربرد و مناسب بودن مدل در آولویت بندی راه حلها برای مشکلاتی که کارآفرینان کوچک و بزرگ ایجاد می شود با استفاده از یک مورد مطالعاتی حقیقی نشان می دهد.

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