Application of AHP on SMED for Jig and Fixture Design Selection

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Abstract—**The purpose of this paper is to discuss the application of AHP as a decision-making tool in determining the best design model. Three design models developed were based on the SMED concept which were significant with small manufacturing enterprise jigs and fixtures engineering project., 10 design requirements were considered and used in AHP analysis. The result shows that – the four parameters that were critical measures are gripping, ease of assembly, ease of cleaning and go-no-go inspection, meanwhile easy maintenance was less important for SMED products.**

Keywords—Analytical Hierarchy Process (AHP); Single-Minute Exchange Die (SMED); Design Selection

I. INTRODUCTION

SMALL manufacturing enterprises are one of the main components of the industrial manufacturing scenes in Malaysia. Operating in a small scale, these kinds of businesses are rarely able to compete with the industrial giants when it comes to producing goods in a huge scale. Inferiority in equipment and financial supports are always associated with the small manufacturing enterprises when it comes to competition with these huge industries [1]. Nevertheless, small scale businesses have one big advantage: lesser investment cost needed for both setup and operations, as many small businesses tend to invest only on very critical sectors with costs as little as possible. However, the investors had to decide whether they should invest more on the plant to ensure smooth production flow or to simply minimize the cost at a possible price of reduced product quality. Recent developments on the Single-Minute Exchange Die (SMED) is considered positive as it enables the investors to reduce their costs on plant setups or re-assembly processes as SMED concepts intend to reduce setup costs, while maintaining the production momentum [2]. The improvement of plant with the SMED concepts will enable not just reduced cost, but apparently reduces further strain on workers, who have to deal with a long and complex setup process for a long time. Also, the implementation of Analytical Hierarchy Process (AHP) decision-making tool enables the company to better observe which sector needs critical observation with weightage based on the relevant information on site [3].

The purpose of this paper is to extend the application of AHP in SMED design project. The SMED concept developed by eventually serves as proponent in ensuring the continuous improvement of manufacturing process via quick part changeover. The next subtopic will explain the literature review. Then, it was followed by research methods that included the product development and specific measures for AHP analysis. The result and discussion explain the overall findings of the project while the last subtopic is the conclusion to sum up the outcome from this project.

II. LITERATURE REVIEW

One of the principal challenges facing organisations today resides in their ability to choose the right and consistent alternatives on maintaining their strategic alignment. In any

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particular circumstances, making the right decisions has become one of the scientific and technological challenges [4]. Therefore, AHP was introduced and has become one of the tools used in project selections and priority-making. In the 1970s, Thomas L. Saaty developed the AHP and since then it has been extensively studied and used for decision-making in complex circumstances, where people work together in the decision-making process when human perceptions, opinions and consequences have long term effects [5-6]. Multi-criteria programming using AHP is a decision-making technique in complex environments, where many variables or criteria are taken into account in prioritising and selecting alternatives or projects [7].

AHP is known to be the appropriate system for assessments and there are reasons behind the use of AHP to focus potential suppliers on relative positioning. In order to use AHP, the evaluation should apply a proportional scale to all criteria and suppliers [8]. The accuracy of these comparisons depends on data available to the evaluation and the leader's depth of understanding on the problem [9]. Since the evaluation is largely probable to contain finished data on all the elements of the decision or a comprehensive understanding of the problem, some or the majority of the pair-wise examinations involve a degree of instability [10]. AHP fits within the class of different devices for selection of criteria.

The application of AHP starts by decomposing a problem to a hierarchy of criteria in order for it to be easier to analyse and compared independently as illustrated in Fig. 1. Following the development of this logical hierarchy, decision makers can systematically assess the alternative solutions by making comparisons on a pairwise for every selected criterion [11]. Specific figures from alternative or human judgments may be used in this comparison in order to obtain subordinate information [12].

The top level of the hierarchy is an overall objective while the bottom level is composed of all possible alternatives. The decision criteria and sub criteria consist of one or more intermediate levels [11]. AHP transforms comparisons and it most frequently transforms empirical into further processed and comparable numerical values. The weight of each factor encourages that the evaluation of each element in the hierarchy is defined. This capacity to transform empirical data into mathematical models constitutes the main characteristic contribution of AHP in contrast to other comparative techniques [13].

The numerical probabilities of every alternative are calculated after all the comparisons have been made and relative weight has been established between all the measurement criteria. This probability determines the probability whether the alternative will achieve the expected objective. The higher the probability, the higher is the possibility for the alternative to meet the ultimate objective of the portfolio [14]. The mathematical calculation involved in the AHP process may seem simple at first, but in more complex cases, the analyses, calculations and analysis become deeper and more detailed [15].

Ho [16] said that AHP has three major processes: hierarchical construction, priority analysis and consistency verification. Initially, by classifying the complex decision issues of multiple criteria into its components, the decision-maker can organise multiple hierarchical levels. It was then followed by a combination of all clusters of the same level in a pairwise, using the know-how and knowledge of the decision makers.

During comparative procedure, inconsistencies may occur, with peculiar or subjective judgements involved [17]. Therefore, in ensuring consistent judgements, the consistent checking process is equated with pair measurement of the consistency of the level of comparisons. The consistency ratio is calculated and if the result exceeds the limits, each comparison in pairs must be examined and revised again. The attribute of a priority ranking for each criterion can only be found by synthesizing the judgments if the consistency ratio can prove that the pairing comparison is consistent. In this stage, the design selection will be based on SMED approach. Fig. 1 shows the overall AHP-SMED processes.

There has been lot of work done in detail for the SMED methodology in many industries and also suggest that the effective implementation of SMED precisely requires a number of fundamental needs, they are: teamwork, visual factory control, performance measurement, and continuous improvement about the role of manufacturing environment in execution of SMED concept. The relationship between changeover and production levelling has also been studied and it was concluded that as the batch size decreases, the cost of each part will increase, since the changeover time will be spread over fewer parts. This leads to rising manufacturing costs when changeover times are high and it also discussed the detail changeover analysis and concluded that in making a part, every degree of freedom of the machine must be specified and fixed [18-19].

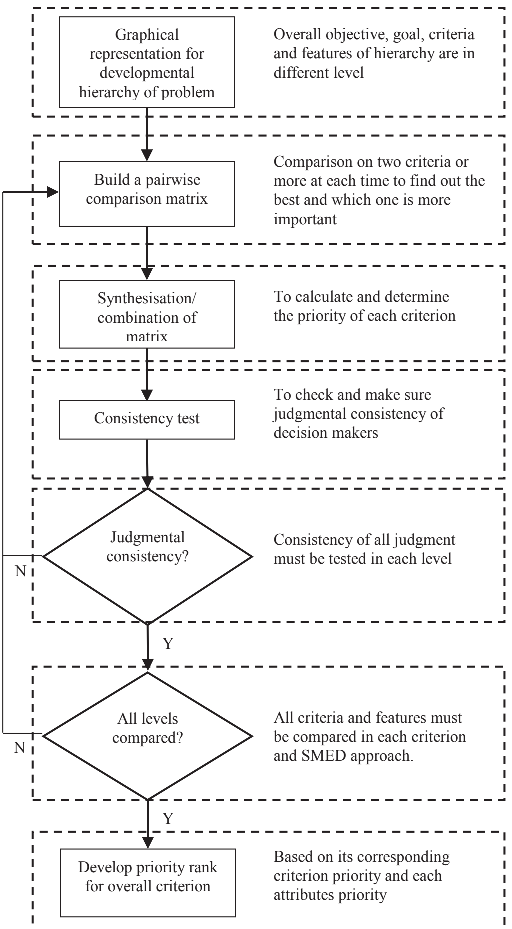

Fig. 1. AHP-SMED flowchart

Vaidya and Kumar [8] also provide a further explanation about the AHP process, in which they stated that AHP is an Eigen value approach to make a comparison, in which it is a multiple criteria decision-making instrument. AHP also offers the method of adjusting the numerical scale for quantitative and qualitative measurement performances. The scale ranges from 1 to 9 and as the number increases, the degree of importance will also increase. The basic step in AHP is shown in Table I.

III. RESEARCH METHODS

The project starts with marking the problems and the objectives of the project, as a whole. Literature study was performed to understand the concept of AHP, SMED and jig and fixture design selection. Then, the project continued with an industrial case study. The company was established in 2010 in which in its earlier phase, its businesses include machine maintenance and part fabrication. In 2012, the operation then starts to include large volume manufacturing operations until today. Throughout its timeline, the company mainly utilizes conventional machining methods for its entire product with lower precision priority whereas outsourcing method is used for high-precision products (such as measuring gages and gears). The company specialized in industrial supply part maintenance, as well as automotive part productions. This company mainly utilizes conventional arms of cutting machines during operations. The purpose of the case study is to identify the actual problem faced by small automotive part manufacturer and specify the design requirement of the tools.

The study involved technical inspection on existing tools, jigs and fixtures to produce an automotive part as Fig. 2. The product, also known as block cross member, is a steel hollow block which was used as an attachment slot for the gripping screw of the towing crane during the lifting process. The work nature of the part renders is highly critical as any flaws during the towing process will harm both infrastructures and lives. The block cross member is usually installed on the front lower part of the car, practically on the car bumper of body in white (BIW). Made using mild steel, the process involved ranges from cutting to several stages of milling and tapping, and all the processes were manually done. The working nature of the part also requires that all parts involved to undergo 100% inspection in order to ensure that all parts are specifically safe to be installed on the bumper assembly. Although many projects look similar, each and every one of them is unique. The company is firm with project-based processes and sell themselves on the basis of their capabilities rather than on specific products or services offered. Generally, the production company's workflow in manufacturing block cross-member part by the company consists of three main stages which are detailing the order, fabrication and quality check.

The operation carried out by the plant includes a number of jigs and fixtures deployed according to the machining orientation during operations. Machines, and jigs are then observed and recorded. Then, the recorded list of jigs and fixtures are then analyzed in order to rate them in term of the critical level of the tools by using AHP, a design tool used to identify the best design scope to cover.

TABLE I. STEPS INVOLVED IN ANALYTIC HIERARCHY PROCESS

Step	Detail
1	State the problem
2	Expand the objectives of the problem
3	Identify criteria that influence the behaviour
4	Structure different level of hierarchical problem considering goal, criteria, and alternative.
5	Calibrate the compared element into numerical scale.
6	Compute to find maximum Eigen value, consistency index, consistency ratio, and normalized values for all criteria.
7	If maximum Eigen value, consistency index, and critical ratio are satisfied, normalized value will be taken as the decision or repeat the process.

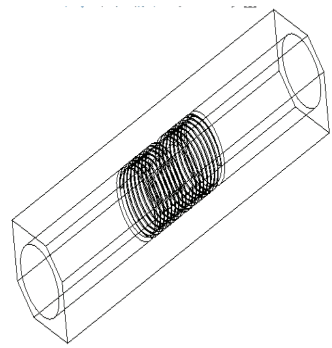

Fig. 2. 3D Wireframe Model of the Block Cross Member

The data collected then used to create several concepts that befits the vice jig improvement requirements. The design must include which components are maintained and which components must be redesigned in order to fill the SMED requirements. Then, the concept selection was carried out in which the only concept that best fits the requirement that allowed to proceed into the next stage: 3-Dimension (3D) Modelling. Post-selection adjustments also required in order to fit the concepts further into the requirements.

The next stage after concept selection is the detailed design. The selected concept is further detailed in order to create a working 3D model that can be manipulated for other functions such as assembly and automated manufacturing. The primary software suitable for this task is Solidwork 2016, a virtual designing software specifically suitable for 3D design, in which can be manipulated either for design assembly or machining. The newly created 3D models that was based on the previously stated concepts then can be manipulated for AHP evaluations. Focus grouped discussion was organized among project team members to agree the best selection for new jig and fixture design.

IV. RESULTS AND DISCUSSIONS

A. *Observation Analysis*

In the quality check section, through a decision process, the workpiece is examined using a jig to ensure that the workpiece is in accordance with the specification. This decision will yield a yes or no result based on the quality check observation. If it is a yes, this means that that the workpiece will be continued through the next process which is the packaging process and then continue for the end process before it is sent to the customer. On the other hand, a no result may mean two things, reject and rework after the decision is made, yes for rework and no for reject. The Rework process is a workable material in which defect can be repaired like a rough thread and size of the finished workpiece might be too large. The workpiece will be shipped according to an identified and marked damage and will undergo a re-machining process. Unlike the rejection which meant that the problem identified could not be resolved (defect cannot be repaired) as the workpiece was too small in size and the threads were damaged, the workpiece would then be disposed. From the problems mentioned before, it is often a rework process and rejected because of the workpiece's defect.

There are two parts where rework process often occurs labelled as X and Y (Fig. 3) which are the threading process and cutting edge process. Within 4 months of observation on the given secondary data, the total amount of the rework process is equal to 210 pieces, for both point X and Y. Based on this, rework process may take between 4823 seconds during March, 5005 seconds during April, 4732 seconds during May and 4550 seconds during June for both problems through related processes for point X and Y. The total time recorded is 19110 seconds which is equivalent to 5 hours 31 minutes. If it is viewed again based on the wasted time from this process, it is equivalent to a complete process for 29 to 30 products of block cross member. It is a waste if this continues.

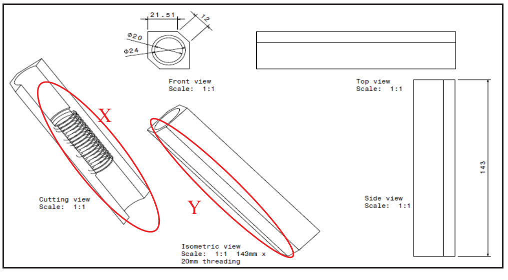

Fig. 3 Rework and Reject Point

Regarding product rejection, from the observation, there are only 33 pieces and it is not a significant amount. However, the amount might be harmful to the company in terms of material, time and labour. The percentage of rework and product rejection problems which indicate that the largest population to be avoided is process rework is 86% compared to rejection with only 14%. From this problem, Table II shows the reason for this rework process.

TABLE II. CAUSES OF THE REWORK PROCESS

Point	Description	Cause
X	Female thread is too abusive and cannot be inserted by male jig screw	The cutting tool blade is not sharp The point of the tip (angled) or the work piece is tilted and not straight
Y	The cut corners are too little and rough that they cannot get into the jig	The tool points are broken or blunt Do not cut according to the specified size

From the observation on data obtained, the rework process was conducted to fix errors and corrections are made to the product and to find out some of the causes which led to these problems. For point X, when a jig screw is inserted on the product, there was difficulty for the screw to properly function through the female thread which has been made. This is due to the cutting edge of the tool in making the thread not sharp and cause the resulting thread to be rough. In addition, the position of the cutting tool/s eye or the workpiece is tilted and this might also cause this to happen and produce a slender female thread. On the other hand, for point Y, the problem is that the vertices cut is too little (not according to the size of the cut) and the surface is rough and that makes it unable to enter the jig. This happens because the tool points are broken or blunt during the cutting process.

The rework process and rejection will not take place if the problems identified did not happen and solved. The rework process must also be avoided and it will give more time to increase the quantity and quality of product production. In addition, the male jig must be changed and a proper male jig screw must be used. The existing jig used is not suitable because it only uses conventional screws as jigs.

B. Assessing the Alternatives

There are several alternatives regarding the passing standard of the defected parts to the customer. Firstly, the improvement of the inspection method, in which the product box must be visually and physically inspected using hand. However, this method doesn't highlight the overall quality situation of the whole production batch. The issue of workers disregard the instruction is still dominant as there's no clear visual sign of how to decide if the part is defected. There is some case of defect detection on the customer's line and this highlights the critical need for procedural changes.

Another alternative with regard to fool proofing quality is to mark the confirmed batch with the "S' mark, to signal that the parts have passed the quality gate. This method is effective as it greatly tells the difference whether the part has passed the quality inspection or not. However, the method has its own critical flaws. Even though "S" has its own significance as a mark that the part has been confirmed, it doesn't really have any clear physical link to the thread inside the hole. The marking can be made even when the operator is in fatigue condition and having lack of visual awareness, thus it can probably cause some defected parts to pass into the customer line. This prompts the company to find a new fool proofing technique in order to counter the intended problem.

The company then insisted to use a suitable fool proofing technique of their choice. They must only choose those that can only be created only if the thread is no longer there. In the end, they decided to choose a scribing technique. Scribing is a marking method in which a sharp pin is pointed to a surface and being dragged along the surface to create a specific line or pattern. This technique is usually used to mark the line for manual manufacturing method. However, in the company's case, it is simply used to signify the existence of thread inside a hole. This technique, compared to pen marking or dot denting, requires a highly specialized tool which can do both thread testing and scribing at the same time.

C. Setting the Tool Requirement

The intended tool has its own requirement and restriction. In designing a tool, justification of designing operation must first be made in order to ensure the intended design is highly critical and not another wasteful mark for the company, other than providing insights on how the tool is going to be used. The justification must include how it can be repetitively used for a very long time, and how the tool can solve the fool-proofing issues regarding the product. Costing and tool lead time are also important as both elements are critical in the upstarting stage of the whole tool designing process.

The next stage is to determine the tool required in the designing process. This step is important as it determines the critical aspect of the design, as well as a scoring point if several design proposals are presented. The whole tool requirement elements can be obtained directly from the interview with the quality control operator, who are also in charge of operating the packaging sector. After spending some time interviewing the worker, several aspects of the design are highlighted and plotted into the table. Each aspect was also given priority ranking based on how critical the aspects are and how sustainable are these aspects to the manufacturing system in the plant. The Table III below shows the aspects/ requirement and their respective ranking.

TABLE III. DESIGN REQUIREMENT FOR THE SCRIBER TOOL

No	Design aspect/requirements	AHP Code
1	Gripping	R1
2	Ease of assembly	R2
3	Tight pin attachment	R3
4	Lightweight	R4
5	Single-handed grip and lift	R5
6	Ease of cleaning	R6
7	Ease of Maintenance	R7
8	Adjustable pin	R8
9	Able to perform go-no-go inspection	R9
10	Can perform a process in a minute	R10

All of these requirement criteria are used as selection criteria in selecting the optimum conceptual design for all models. They will then develop to respond to certain model that has the highest score performance. 10 criteria have been pointed out, and all of them are linked together with all five conceptual design which also known as the selection alternatives. Next, numbers of pairwise comparison matrices are developed for all requirement criteria and all the alternatives (Model A, Model B, and Model C), which are conceptual designs with regard to all the selected requirement criteria. The developed pairwise comparison is shown by using a set of tables. For each pairwise comparison, consistency ratio is computed in order to check the judgment's consistency.

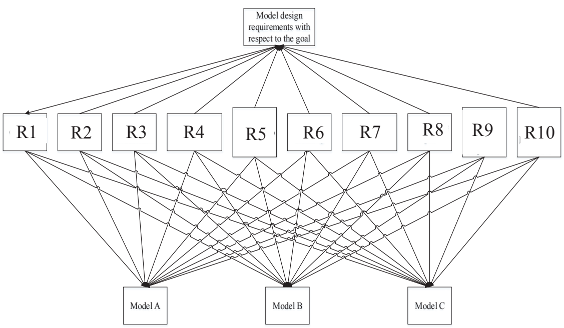

Fig. 4 Hierarchical structure for AHP for model design requirements

Gripping essentially defines as to hold something firmly. In a product design, a product which will be gripped must be comfortable enough so that there will be no slightest feel of pain or strain when it is hold, at least for a certain period of time. Parts which do not possess gripping comfortability tend to cause their user to have hand fatigue, in which the user's hand will become weary due to its prolonged use of non-ergonomic gripping tool. Gripping a tool in a prolonged term requires a design that basically can delay the pain causes by strain due to prolonged use of it. Thus, a good ergonomic gripping design must take into account the shape of hand, and which part of hand is involved in the gripping process.

Tool operation is essentially a critical process which is basically operated after it is assembled. Assembling parts of the tool can be considered the very first step in operating the tool. Tool assembly is important as it determines the efficiency of the tool. Tool assembly duration might be influenced by several factors which are the number of parts and the number of time taken. Too many parts can make assembly a lengthy business, while too much time taken for each part can also delay the assembly, and this is usually due to the complex shape or assembly process of the part. A good assembly is an assembly which is not too complex in part and can be assembled in a short period of time.

In creating a scriber, a secured scribing pin is needed in the first place. As a conventional table scriber tool, it must be able to perfectly fit into its attachment slot in order to function properly. Compared to the table scriber tool, the scribing pin will not scratch the paper because it has metal surface. In addition, the scribing operation will be repetitively done as inspection done inside the plant requires total scope of the finished product, which may be for around hundreds a day, thousands at most. A Repetitive use of the product requires the attachment to be firm and fixed, even after it is involved in thousands of operations.

The scribing tool must be lightweight enough so that it can be carried single-handedly. In conventional situations, quality control tools may include table-based operations which are usually applicable for partial inspection. In this case, however, minimum manpower will require extra mobility for a flexible working situation, in which some workstations may be required to do more than 2 process in a single cycle. The proposed scribing tool however must adhere to these work natures to be fitted into the process.

The proposed scribing tool must adhere to the ergonomic demand of the workstation. As the lightweight criteria must be marked, the handling design must also be taken into account for an efficient ergonomic gripping design. Lightweight and easy gripping, tools will make quality control working procedures easier and quicker. These tools, however, should not be compensated with cheaper materials such as aluminum as these materials tend to bend while they are under immense stress, thus rendering the tools defected.

Cleaning is an essential process to end the procedure. These matters, however, will usually put into light if any of these tools wore off or improperly functioned. For these scribing tools, it must be easy to clean, since humid and stuffy working environment may require these tools to be easily cleaned of dirt, dust and chips, which usually contributes to the clogging inside the internal compartment of the mechanical tools.

An efficient working tool must be easy to be maintained in order to ensure that no additional cost will be spent upon tool maintenance. Tools which require frequent maintenance are not sustainable and are seen as an additional burden in term of manpower, time, and commitments.

Adjustable scribing pin is critical to the repetitive working action nature inside the workstation. Scribing pins are usually sharp pointed, and when they are in contact with metal, and later dragged. The sharp point will slowly wear off after a certain period of time. We must bear in mind that fixed pin is apparently not a sustainable option as a tool with fixed main part may wear off and can be rendered obsolete when it is no longer in use as the main part cannot be changed or adjusted.

Go-no-go tool is an inspection tool used to test whether inspected element adhered to the quality specification. Most go-no-go tools act as a testing tool, rather than accompanying marker. This signifies that the work piece has been tested. The scriber, alongside go-no-go concept, when combined, will provide an excellent combination which would ease the work process of quality control sector; both inspection testing and marking can simply be made using a single tool.

The proposed scribing tool must be able to perform a process on any part in a quick shot, as there may be hundred products produced in a single day. Quick inspection and marking had to be done in preferably less than a minute per part. The time duration to perform procedures for each part may be reflected by the number of process per cycle, the insertion complexity, or the number of rotations for the go-no-go bolt to fully enter the hole.

D. Design Concept

In designing concept creation, firstly, it is crucial to have strong justification in order to ensure that the creation of the product is in whole, reasonable and relevant to the surrounding panoply. Next, criteria or requirements must be determined, preferably by the potential user of the tool at the first place. Based on the criteria selected, the idea for the design concept is created by using any CAD software available. Rough sketching is the actual first step in designing concept creation but since weight analysis in every concept is needed especially the one that reasonably justified for the whole concept creation. In a usual fashion, the design concept should not only consist of one candidate. This is for exploring whether there is another option in terms of material, geometric, shape, complexity, assembly, etc.

In this case, design concepts are created after taking into account all the previously mentioned concepts. The design concept evaluation, however, depends on how critical the intended features are and how they adhere the previously mentioned criterion. However, if a design concept is mostly the same, only differ in parts, or based on the previous models, only new parts will be detailed in the proposal. The evaluation of the concepts later on will be made via AHP analysis methodology, in which all the concepts will be compared in pairs in order to evaluate the critical level of each concept. Concepts which receive the most critical values of all concepts will be selected and evaluated for further discussions, particularly in marketability and sustainability aspects.

E. AHP Analysis for Model Selection

For the selection analysis, firstly, it's critical to re-check back into the requirement as stated in Table IV. The whole requirement then must be used to justify all 3 models for the design selection (see APPENDIX). AHP analysis is done in term of each requirement and in the end, models which score the most are chosen as a preferable model. The chosen process then will proceed further for further analysis in regards to marketability and sustainability. The Table IV summaries the AHP analysis of those 3 models with their respective requirements criterion.

The overall priority value for all three models was calculated and shown in Table IV. In order to get the overall priority value for the model, each priority vector of the model is multiplied with each priority vector of the requirement criteria. Next, the multiplied value is summed together to get the overall priority value. After the calculation for overall priority value for each conceptual design is completed, the alternatives are sorted based on their level of priority value which is from the highest to the lowest value. After completing all the calculation and ranking process, the result is drawn and based on this, the model which has the highest rank performance is Model C with the score of as much as 35% of priority index if compared to other conceptual designs. The second highest rank value is Model B with the score of 34% and followed by the amount of 32% from Model A.

TABLE IV. OVERALL PRIORITY VECTOR FOR MODEL SELECTION RESPECT TO EACH REQUIREMENTS CRITERIA

	Gripping	Ease of assembly	Tight pin attachment	Lightweight	Single handed	Ease of cleaning	Easy maintenance	Adjustable pin	Go-no-go inspection	Process in a minute	**Overall Priority Value**
Requirement Priority	0.13	0.14	0.08	0.1	0.09	0.12	0.07	0.08	0.12	0.08	
Model	Priorities comparison with respect to each of requirements criteria										
A	0.56	0.20	0.33	0.43	0.17	0.29	0.11	0.33	0.33	0.33	**0.32**
B	0.32	0.20	0.33	0.43	0.17	0.57	0.35	0.33	0.33	0.33	**0.34**
C	0.12	0.60	0.33	0.14	0.67	0.14	0.54	0.33	0.33	0.33	**0.35**

V. CONCLUSION

The criteria of design requirement for the scriber tool were identified for the weightage prioritizing calculation of each requirement listed using AHP tools. Analysis of AHP is done to choose the best conceptual design based on three designs suggested. Based on the higher weightage, a rank the suitable requirement conceptual design in order to solve the problem from the high rework and rejection volume. Design from the criteria of Model C is based on design requirement for the scriber tool implementation which possess a higher ranking compared to the others design. It shows that Model C is the best model from the conceptual design which needs to be done in order to solve the problem through high rework and rejection volume.

APPENDIX

A. Model A

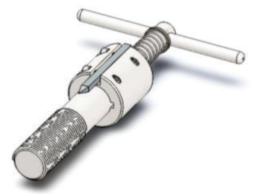

Fig. 4 Isometric view of Model A

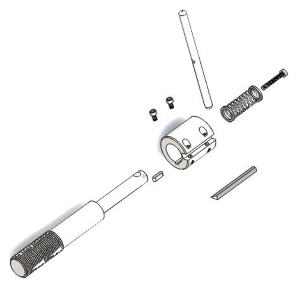

Fig. 5 Exploded view of Model A

B. Model B

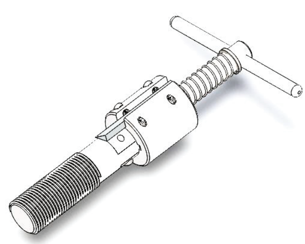

Fig.6 Isometric view for Model B.

Fig.7 Exploded view of the assembly for Model B.

C. Model C

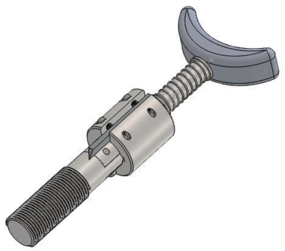

Fig. 8 Solidwork model for the Model C (Isometric view)

Fig.9 Exploded view of the assembly for Model C.

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