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Design of Reverse and Missing Jaw Detector Jig using Analytic Hierarchy Process (AHP)

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Abstract*: A seal manufacture factory located in Ipoh, Perak produces two types of seal available in the factory which are metal and plastic seals. Due to manual assembly, human operator tends to get fatigue for doing repetitive task in one long shift. When this occurs, minor error such as misplace or wrong orientation of jaw will occur. Moreover the jaw sometimes can be missing during transportation of work – in – progress to another process. The objective is to design a jig that have the ability to detect reverse and missing jaw so that the finish product which has the quality problem will be prevented from being shipped to customers. The jig must also have a flexibility to be used for other plastic seal product. For methodology, each and every stage was explained in detail. In result and discussion section, House of Quality (HOQ) was used to determine the highest criteria weightage. The important criteria which will be carried forward to Analytical Hierarchy Process (AHP) are 15.9% on flexibility and ease of maintenance, 15.4% on both ease of use and longevity of jig usage, lastly 15.2% for accuracy checking. The result obtain after AHP computation are Design 1 with 20.7%, Design 2 with 13.7%, Design 3 with 22%, Design 4 with 27.1% and Design 5 with 16.5%. Design 4 is selected due to the highest weightage after computation. Final selected design was justified according to characteristic needed in objective.

***Index Terms*: Analytic Hierarchy Process,House of Quality, Jig Design, Defect Detection,**

I. INTRODUCTION

Jaw is a component present in the plastic seal. The function of this jaw is to prevent the pull back of insertion and make sure a strong lock between the seal and the product that needs locking. The jaw is a metal part which being inserted in the plastic seal before being covered with plastic cap. Figure 1 is sample image of jaw which gives higher strength for the seal when locking.

Figure 1: Jaw used for plastic seal

The jaw is being placed in a slot and being covered by a plastic cap through the process of ultrasonic welding. Figure 2 shows the assembly of jaw and cap in plastic seal.

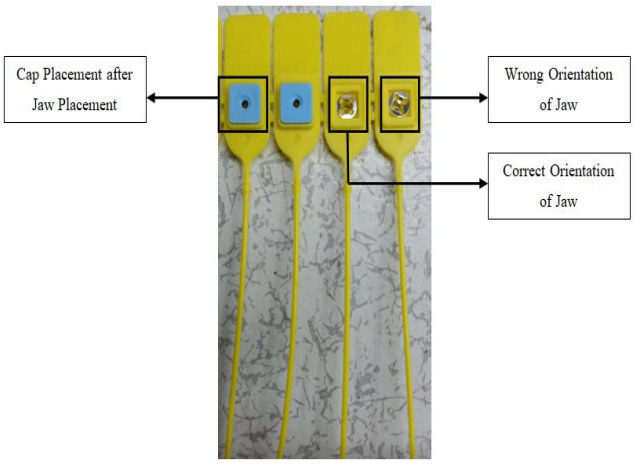

Figure.2: Image of placing jaw and cap in plastic seal

The impacts of wrong assemble will caused customers to have hard time to use the seal. Some issues occur where during the assembly of jaw and cap after ultrasonic welding, few cavities are losing the jaw, hence making the locking impossible to be done. Figure 3 shows the locking when the jaw is in wrong orientation.

Figure 3: Locking of seal with wrong orientation of jaw

The white cap shows the jaws were placed in wrong orientation. When this problem occur, the seal will not functioning well.

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The objective of this experiment is to design a jig to detect reverse or missing jaw detector jig and select the best design of jig. By having this jig, the defect can be detected and set up time or checking time can be cut down because it is a type of waste which gives no value added [1]. There are several sensors used to be implemented in the final designed jig. The sensors suitable are machine vision system [2], fibre optic laser scanning system [3] and piezoelectric sensor [4].

However, all sensors mentioned were costly to be implemented. This jig may not require expensive sensor instead to embed a pin on the jig and make the pin to touch the jig. Once the pin touches the jaw, the operator may observe that there is a defect in the plastic seal.

II. METHODOLOGY

In this part, flow chart is developed to show the whole process of fulfilling this research work. Flow chart is used to analyze, designing, documenting and managing the whole process. This is important to determine the stage that need to be taken in order to complete the research. This flow chart give aid when there is a problem occurred during the research. This flow chart will give aid to which stage to be checked and to remind the scope of this research.

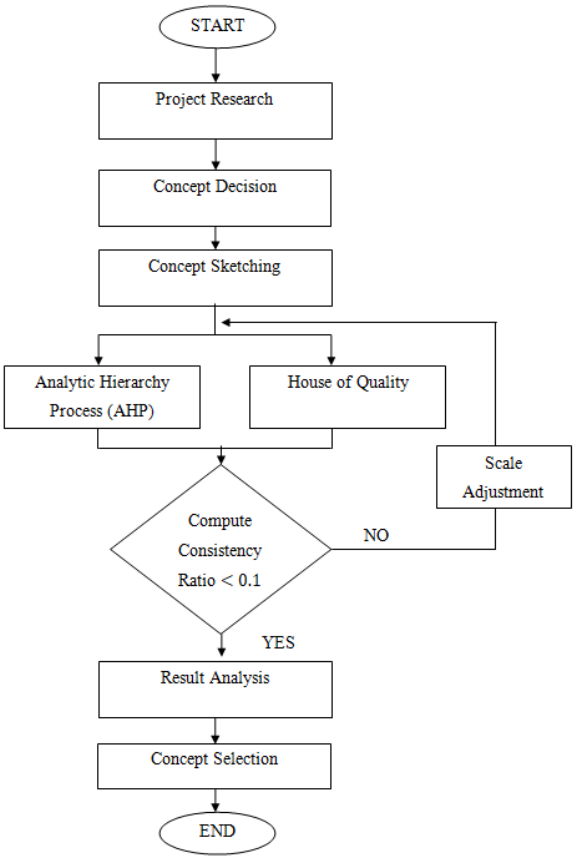

Figure 4: Overall research method

After the introduction of the project which is for the purpose of introducing the information regarding project title, next is to locate information. All information is gained from books, journal, websites, internet and also article. The research is to use the information in order to help with the few concept design that will be sketch. This information is narrowed down according to scopes which have been set in Chapter 1 so that the research area is not being broad. Few researchers have done a splendid job in order to determine the best selection according to the criteria. The result from previous journal will be studied through in this stage. This information will be useful from the beginning of concept designs until the last concept selection. Few concepts being mention in a journal regarding the usage of jigs and how it can ease the process during assembly in a production line. Therefore few criteria were acquired from both customers and company management to how the design should be shaped like. The jig should have flexibility, light, easy to plug and unplug, will not damage jaw and can detect both reverse jaw and missing jaw. The criteria being notify to the suitability of usage of jig in production. In this stage of decision, basically the mechanism types are being listed out and implemented in the next stage which is the concept sketching.

Some criteria have been added for the purpose of ease being use by the operators in the assembly line. From all the criteria, sketches being made in order to fulfill the desired jig. Out of many sketches, few will be selected or merge into one design. This is due to some mechanism can be integral and can fix into the same jig, rather than having two different jigs. Several sketches which are selected being drawn using AutoCAD software to have graphical view on the jig will look like.

From several sketches being drawn a proper method is being use to select and develop the concept jig drawing. This tool basically is much more accurate than just randomly screening and scoring. This tool also offers comparison from a design to another basically in criteria. If there were five criteria,, the pairwise comparison is being made for 5 times but for a different criteria. This is quite useful because, the user of this tool can have another pairwise to set higher weightage on the criteria. Since the objective of this research is to have high flexibility, therefore, the weightage can be manipulated to set the mentioned criteria to be the most important. Table 1 shows the scaling of Analytic Hierarchy Process (AHP).

Table 1: Scaling of AHP

Categories	AHP	
Equally Important	1	1
Intermediate Preference	2	$\frac{1}{2}$
Moderately More Important	3	$\frac{1}{3}$
Intermediate Preference	4	$\frac{1}{4}$
Strongly More Important	5	$\frac{1}{5}$
Intermediate Preference	6	$\frac{1}{6}$
Very Strong More Important	7	$\frac{1}{7}$
Intermediate Preference	8	$\frac{1}{8}$
Extremely More Important	9	$\frac{1}{9}$

First Step in AHP is to place weight according to the scale provided in Table 1 under the column Traditional AHP. Carry out pairwise comparison by placing whole number to superior criterion and reciprocal judgment for least superior.

The weights are sum according to column and divide with every weight under the sum column resulting to obtain a sum of 1. Later, the weights are added by row where all of the different alternatives are added to obtain one value of final weight age with respect to the row. Then, consistency checking was performed.

Calculate the Eigenvalue (λ_{max})

λ_{max} = Priority Value Criterion 1 (Weight Criterion 1) + Priority Value Criterion 2 (Weight Criterion 2) + …..+ Priority Value Criterion n (Weight Criterion n)[5].

Calculate Consistency Index(CI)

$$CI = \frac{\lambda \max - n}{n-1} \quad (1)$$

Calculate Consistency Ratio (CR)

The value of RI is referred in Table 2 according to value,n.

$$CR = \frac{CI}{RI} = < 0.1 \quad (2)$$

Table 2: Random Consistency Index Table

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

All the values of weightage and criteria are multiply and add to obtain the final value. The biggest value is to be selected as the best choice or the highest in rank.House of Quality (HOQ) is a diagram which resembles a house. This method is used to determine the relationship between customer needs and product capabilities which can be improved by the company. Utilize as a planning matrix to relate what customer wants from the company. Therefore correlation mark is being used to determine which is highly positive to highly negative. Consistent ratio is one of the steps which is a must to be performed in Analytical Hierarchy Process. The purpose of having this is to avoid randomly assign scale which sometimes can be illogical. The scale can be set nearby to each other so that the difference gap is not too big. This however would give the user to have better selection of which design should be selected. The normalization of value will be almost consistent even though the designs have almost similar type of mechanism or shape. Finally the result will be finalized and the best concept selection with highest mark was selected.

III. RESULT

There are 5 designs that were sketched. Each design was explained on the method of operation. This section displays the final output of HOQ and AHP in order to select best among 5 concept design.

A. Designs for Reverse and Missing Jaw Detector Jig

Figure 5 displays the first jig design. There are 20 Light Emitting Diode (LED) for the purpose of identifying if there is a presence of jaw. Red indicates that there is no presence of jaw and green to signal the operator that the product is complete with jaw in it. Ignition switch to turn on the jig or else the red light will be keep on open signaling the operator that the no jaw in that plastic seal. Screw mounted on the plate act as stopper so that the mat does not move about during inspection stage. However, 10 yellow colour cubes are the exact position to place the mat facing the insert direction.

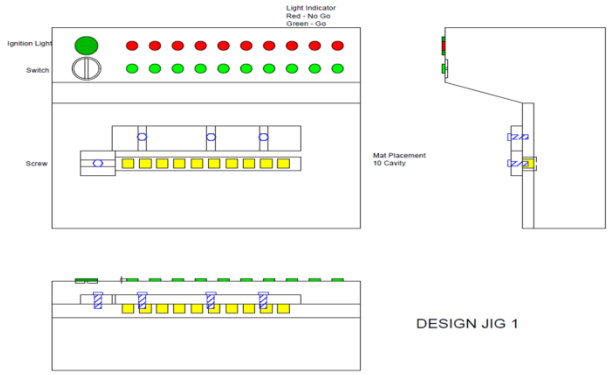

Figure 5: Concept jig design 1

Firstly, adjust the stopper according to the length of product's tag. Then adjust the yellow colour cube according to the cavity length. Turn on the ignition switch to power up the jig. Place the mat by guiding each cavity tally to each cube. Red ignites showing no jaw and green ignites jaw is present. Weakness of this jig is that this design unable to identify the orientation of jaw and use up excessive components which are the LED units. Figure 6 shows the concept jig design 2.

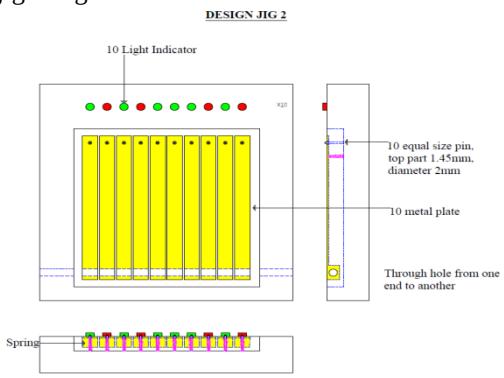

Figure 6: Concept jig design 2

There are 10 Light Emitting Diode (LED) for the purpose of identifying if there is a presence of jaw. Red indicates that there is no presence of jaw and green to signal the operator that the product is complete with jaw in it.10 long rectangular plate with through hole. The hole is slide over with one metal rod in it to hold put the 10 metal plates. The distance between plates is adjustable according to the cavity. 10 pins are implant with the jig from the base. The pin is readily mounted and unable to manipulate according the distance between insert. 10 springs were mounted below the plate to levitate at the front part of plate. The method to use is firstly adjusting the plate according to cavity's distance. Place the mat by guiding each cavity tally to each pin. Red ignites no jaw and green ignites jaw is present. When the plate presses the spring signify that the orientation of jaw is correct. If else, the jaw in wrong orientation and the cavity with rise up not having the same level as other cavity. The disadvantage of this jig is less flexible due to the pins mounted on the base and the circuit is on when a metal surface touches any of the pin. Other weakness is that the spring will reach to a stage where it can retract to original position.
Need high maintenance.

The operator must carefully use this jig for its pointy pins may harm them.

This will consume more time because the insertion holes need to be properly place through the pins. Figure 7 shows the third design concept of jig.

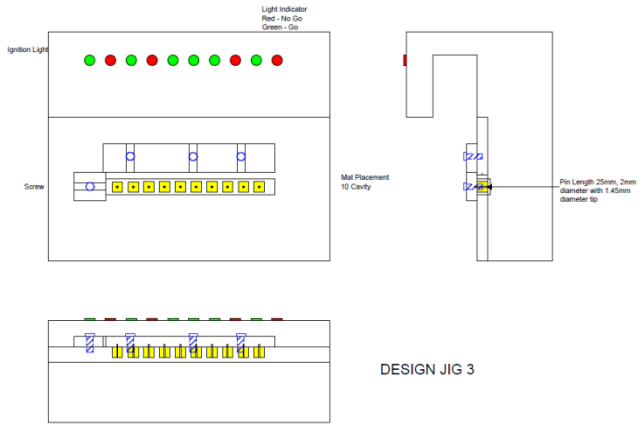

Figure 7: Concept jig design 3

There are 10 Light Emitting Diode (LED) for the purpose of identifying if there is a presence of jaw. Red indicates that there is no presence of jaw and green to signal the operator that the product is complete with jaw in it. 10 yellow cubes with pin mounted to it. This is for placement of each cavity facing insert on top of the jig.Ignition switch to power up the jig.Screw mount on the plate act as stopper so that the mat does not move about during inspection stage. This stopper can be removed for maximum placement of seal which have long tag. The method to use is firstly the slider was adjusted according to the tag length. The cubeswere adjusted according to the cavity's distance.Place the mat by guiding each cavity tally to each pin. Red ignites no jaw and green ignites jaw is present. The cavity will rise up if the orientation is wrong and others will be lowered and same level when jaw orientation is correct.However the disadvantages are need to be very detail in fabrication of jig due to small size of pin diameter and placement of LED. Need extra machining for the L – shaped base which hold the LED.The operator must carefully use this jig for its pointy pins may harm them. This will consume more time because the insertion holes need to be properly place through the pins. Figure 8 shows the fourth conceptual design.

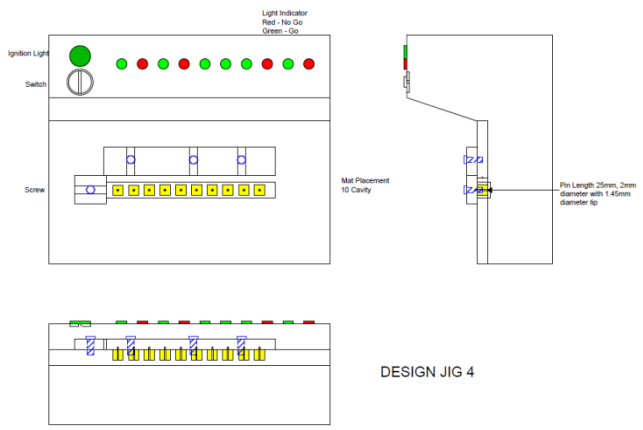

Figure 8: Concept jig design 4

There are again 10 Light Emitting Diode (LED) for the purpose of identifying if there is a presence of jaw. Red indicates that there is no presence of jaw and green to signal the operator that the product is complete with jaw in it.There10 yellow cubes with pin mounted to it. This is for placement of each cavity facing insert on top of the jig. Ignition switch as usual was used to power up the jig. Screw mounted on the plate act as stopper so that the mat does not move about during inspection stage. Method to use this jig was initially adjusting the slider according to tag length. The cube was adjusted according to cavity distance. Place the mat by guiding each cavity tally to each pin. Red ignites no jaw and green ignites jaw is present. The cavity will rise up if the orientation is wrong and others will be lowered and same level when jaw orientation is correct. However, the disadvantage is the need to be very detail in fabrication of jig due to small size of pin diameter. The operator must carefully use this jig for its pointy pins may harm them. This will consume more time because the insertion holes need to be properly place the through the pins. Figure 9 shows the final concept of jig design.

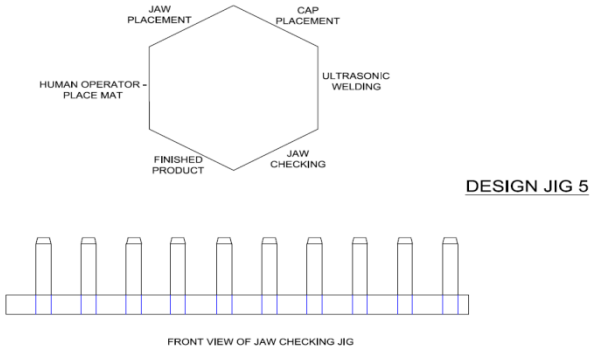

Figure 9: Concept jig design 5

Conceptual design jig 5 have dial indexing table with 6 sides with two switches pressed simultaneously to rotate the table in step motion. Base jig attach to each sides of the dial indexing table. Automated jaw placement mechanism to place jaw in the semi-finished product. Automated cap placement mechanism to place cap in the semi-finished product. Ultrasonic welding machine to weld the cap after jaw is place below the cap. The method of using this machine is easy and automated. Firstly the operator places the mat by tally the insert hole with the pin. Then, two switches are pressed for the table to rotate by step. This will move the empty mat to the next station for jaw placement.Two switches are again pressed for the table to rotate by step. This will move the mat filled with jaw to the next station for cap placement.The next press shifts the mat for the assembly of cap via ultrasonic welding. The next phase is the pin insertion into the insert hole of the plastic seal. If the cavity does not contain jaw, the machine will stop rotate and the operator has to remove the mat for manual rework.The operator will retrieve the finished product and place new empty mat for processing. There are several disadvantages. One of most common thing that needed is high investment needed to design and bring in dial indexing table. It is less flexible because the distance between pin can never be alter. Different jig with pin distance have to be created for different product and cavity length.

The operator must carefully use this jig for its pointy pins may harm them.

This will consume more time because the insertion holes need to be properly place through the pins.

B. House of Quality (HOQ)

HOQ determines which criteria have the strong relationship by correlating both customer and company requirement. Table 3 shows customer and company requirement which will further use in HOQ as shown in Figure 10.

Table 3: Requirement By Customer And Factory

Customer Requirement	Factory Requirement
Ease of Use	Checking Accuracy
Customize Colour	Light Weight Jig
Clear Information (Tensile)	Quick Response Time
Customize Size	Ease of Use
High Sealing Strength	Labor Saving
	Ease of Maintenance
	Upgradability
	Longevity of Jig Usage
	Flexibility

colour pigment and having a mold with different size of seal. Therefore these two criteria place the lowest weightage among the rest. For company requirements that have been listed out. Accuracy checking is necessary so that jaw orientation can be determined. Light weight jig is needed so that it is portable to be brought out and kept it when not in use. Quick response is a criterion so that operator can react when noticed there are defects in mat regarding no jaw or wrong orientation placement of jaw. Next criterion however is necessary for operator in ease understand the Standard of Procedure (SOP) regarding the process. The factory requires cutting down labor. This is for ease of use. When it is ease of use, therefore, maintenance will be simultaneously easy. This is important criterion in order to easy maintain and takes less time. The factory subjects this research to have longevity of jig usage together having high flexibility. Flexibility can be achieved from previous design where the cube can be slide to have different distance according to cavity. The last criterion needed is easily to upgrade so that the jig can become more efficient in checking presence and orientation of jaw in the plastic seal.

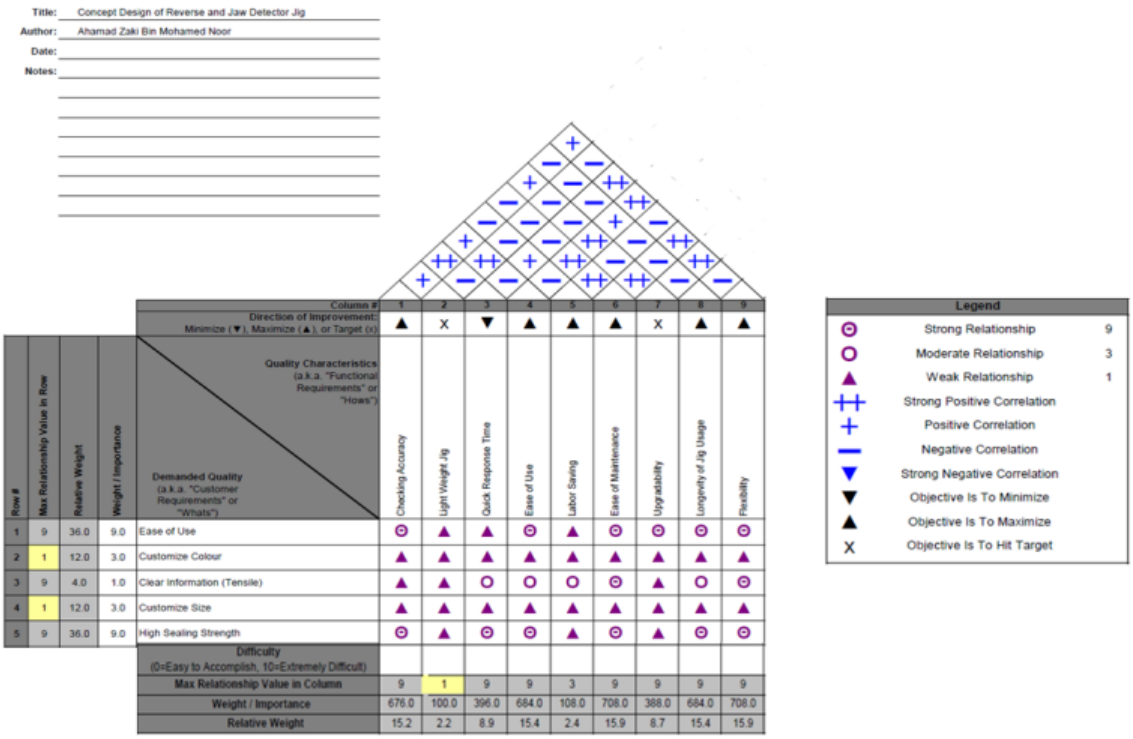

Figure 10: House of Quality

For customer requirement, there are total 5 criteria which have been subjected to the company for their product retrieval satisfaction. The highest weightage is being place is the three out of five which are ease of use, clear information such as tensile strength for seal. The user can identify the strength or load for that plastic seal can withstand. This is easy for the user to identify the seals strength for sealing purposes. The last criterion which is important is that high sealing strength which can be done by placing the jaw and in proper orientation. As for the colour and size customization hard to be done because the stage of producing is by adding

The top five having highest relation is selected to be proceed in the next step of experiment. Notice from the house of quality, the top five criteria is checking accuracy with 15.2%, ease of use and longevity of jig usage are 15.4%. For ease of maintenance and flexibility, the weightage are 15.9%. This are the top five criteria which will be carry forward for Analytical Hierarchy Process (AHP).

C. Analytical Hierarchy Process (AHP)

The decision makers for this research are process engineers. Initially, scaling for accuracy checking to detect wrong orientation or missing jaw is carried out. Table 4 shows the pairwise comparison for accuracy checking between 5 designs. D represent as design.

Table 4: Original Pairwise Comparison Matrix

	D 1	D 2	D 3	D 4	D 5
D 1	1	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{6}$	$\frac{1}{5}$
D 2	2	1	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{3}$
D 3	8	6	1	$\frac{1}{8}$	$\frac{1}{6}$
D 4	6	7	8	1	5
D 5	5	3	$\frac{1}{6}$	$\frac{1}{5}$	1

From Table 4, computation of AHP was carried out. The final result is shown in Figure 11.

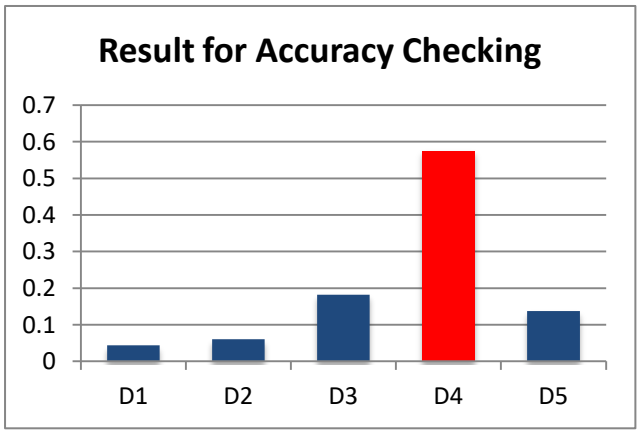

Figure 11: Result for accuracy checking

For this criteria, the highest score win by design 4 with the score of 0.5753. This proves that when it comes to accuracy checking, design 4 is the best jig and the least accurate is shown to be design 1 due to least score. For consistency ratio shows a total of 0.0634 which is less than 0.1. This means that the scaling in the original pairwise comparison can be classified as consistent values. Second scaling carried out is ease of use the jig. Table 5 shows the pairwise comparison for ease of use between 5 designs. D represent as design.

Table 5: Original pairwise comparison matrix

	D 1	D 2	D 3	D 4	D 5
D 1	1	$\frac{1}{5}$	5	3	$\frac{1}{3}$
D 2	5	1	7	8	4
D 3	$\frac{1}{5}$	$\frac{1}{7}$	1	$\frac{1}{3}$	$\frac{1}{5}$
D 4	$\frac{1}{3}$	$\frac{1}{8}$	3	1	$\frac{1}{5}$
D 5	3	$\frac{1}{4}$	5	5	1

From table 5, computation of AHP was carried out. The final result is shown in Figure 12.

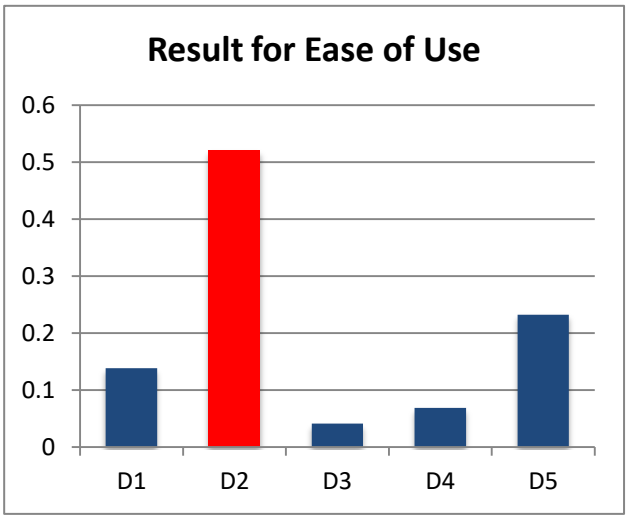

Figure 12: Result for ease of use

For this criteria, the highest score win by Design 2 with the score of 0.5198. Design 2 is considered to be correct in term of criterion easy to use due to the mechanism that being use to check is pin and spring. According to the standard of procedure for the jig in design 2, the operator will just have to place the mat on top of the jig and the insert is guided by the pin. For consistency ratio, the scaling is proven to be consistent because the computed value is 0.0884.Third scaling carried out is ease of maintenance. Table 6 shows the pairwise comparison for ease of maintenance between 5 designs. D represent as design.

Table 6: Original pairwise comparison matrix

	D 1	D 2	D 3	D 4	D 5
D 1	1	5	2	3	4
D 2	$\frac{1}{5}$	1	$\frac{1}{7}$	$\frac{1}{5}$	$\frac{1}{3}$
D 3	$\frac{1}{2}$	7	1	3	4
D 4	$\frac{1}{3}$	5	$\frac{1}{3}$	1	$\frac{1}{2}$
D 5	$\frac{1}{4}$	3	$\frac{1}{4}$	2	1

From table 6, computation of AHP was carried out. The final result is shown in Figure 13.

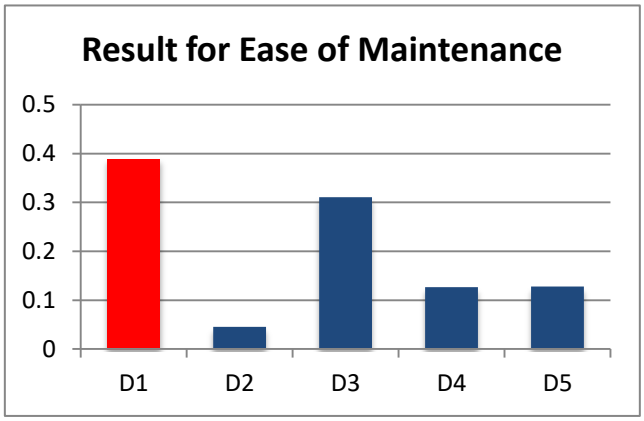

Figure 13: Result for ease of maintenance

For this criteria, the highest score win by Design 1 with the score of 0.3891. This is true because of the design make the technician can easily access the LED. Compared to other design, lot of empty space in the jig make the wire to fall down beneath and hard to reach out afraid it might pull out other wire connecting to LED. For consistency ratio, shows the value less than 0.1 which is 0.0774. This proves that the scale is to be consistent. Table 7 shows the pairwise comparison for longevity jig usage between 5 designs. D represent as design.

Table 7: Original pairwise comparison matrix

	D 1	D 2	D 3	D 4	D 5
D 1	1	$\frac{1}{5}$	2	3	$\frac{1}{4}$
D 2	5	1	3	4	2
D 3	$\frac{1}{2}$	$\frac{1}{3}$	1	2	$\frac{1}{4}$
D 4	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{2}$	1	$\frac{1}{3}$
D 5	4	$\frac{1}{2}$	4	3	1

From table 7, computation of AHP was carried out. The final result is shown in Figure 14.

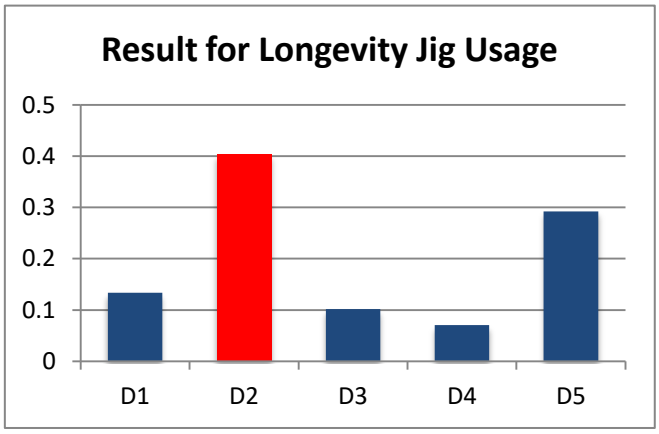

Figure 14: Result for longevity jig usage

For this criteria, the highest score win by Design 2 with the score of 0.4029. Design 2 is actually proven based on assumption being made. Design 2 carried out the as longevity due to two indicators present. There are two indicators to identify missing jaw or wrong orientation of jaw. The first indicator is the LED components which will notify the operator regarding defects to the seal. If the LED is not working, the spring can be used to actually detect missing jaw or wrong orientation. The procedure goes as when the jaw is missing, the pin will go through the insert hole signaling no jaw. For reverse orientation, the pin can identify when the whole mat does not stand in the same level. Some will compress the spring and some will make the plate not to go down. When the plate is not being pressed down showed to be the particular cavity in a mat has a jaw in it but being place in wrong orientation. The consistent ratio for this criterion is less than 0.1 which is 0.0758. This defines the scaling is consistent for all design under this criteria. Table 8 shows the pairwise comparison for flexibility of jig usage between 5 designs. D represent as design.

Table 8: Original pairwise comparison matrix

	D 1	D 2	D 3	D 4	D 5
D 1	1	2	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{3}$
D 2	$\frac{1}{2}$	1	$\frac{1}{3}$	$\frac{1}{5}$	$\frac{1}{3}$
D 3	5	3	1	$\frac{1}{2}$	2
D 4	3	5	2	1	5
D 5	3	3	$\frac{1}{2}$	$\frac{1}{5}$	1

From table 8, computation of AHP was carried out. The final result is shown in Figure 15.

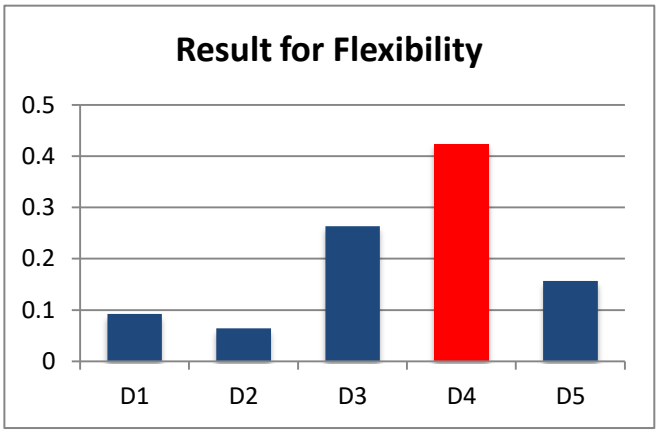

Figure 15: Result for flexibility

For this criteria, the highest score win by Design 4 with the score of 0.4235. This jig has the highest flexibility compared to the rest due to its ability sliding the yellow cubes. This will bring about other product have different distance of insert between cavity to be used in the same jig. The consistency ratio during this comparison gives a value of 0.0729 which is still less than 10 percent.

Last scaling performed by the decision makers is the scaling of all criteria. Table 9 shows the pairwise comparison for all 5 criteria. C represent criteria, where else A to E represent all criteria in same sequence present in paper.

Table 9: Original pairwise comparison matrix

	C A	C B	C C	C D	C E
C A	1	5	$\frac{1}{2}$	3	4
C B	$\frac{1}{5}$	1	$\frac{1}{3}$	$\frac{1}{5}$	$\frac{1}{2}$
C C	2	3	1	5	4
C D	$\frac{1}{3}$	5	$\frac{1}{5}$	1	2
C E	$\frac{1}{4}$	2	$\frac{1}{4}$	$\frac{1}{2}$	1

From table 9, computation of AHP was carried out. The final result is shown in Figure 15.

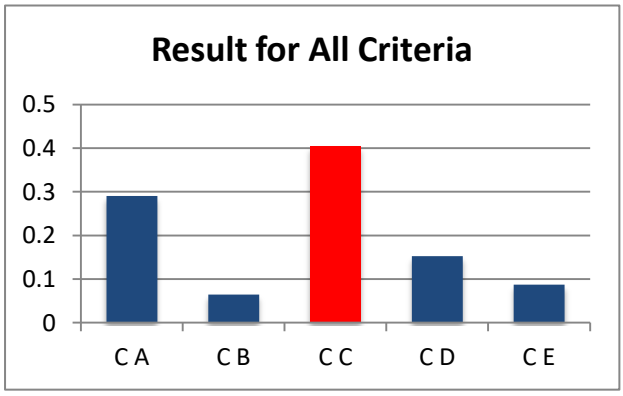

Figure 16: Result for all criteria

For this final calculation, it is important to identify among all the criteria, which show the highest weight. Therefore the criterion is compared to show the highest weight or priority index is given to be Criterion C which is ease of maintenance followed up by accuracy checking, long life of jig, flexibility and last is the ease of use. However the prior criterion that supposed to be on the top should be flexibility. This is because as set to be in the objective is to have high flexibility. Due to scaling consistency, the score are to be changed. The consistency ratio is 0.0965 which is less than 0.1.

D. Final Decision Making

Next step in Analytical Hierarchy process is to compute all the weightage from each design and weightage from all five designs. Therefore, a table have been construct to ease refer the value in order to calculate. This calculation is being done to determine the best score. From the highest score, the particular design will be selected for implementation in the plastic seal production line. Table 10 shows the grouped data.

Table 10: Grouped Data

	C A	C B	C C	C D	C E
D 1	0.0438	0.1381	0.3891	0.1333	0.0920
D 2	0.0606	0.5198	0.0458	0.4029	0.0644
D 3	0.1827	0.0412	0.3107	0.1013	0.2634
D 4	0.5753	0.0686	0.1266	0.0704	0.4235
D 5	0.1376	0.2322	0.1277	0.2922	0.1566
	C A	C B	C C	C D	C E
Weightage	0.2906	0.0651	0.4035	0.1530	0.0878

From table 10, computation of AHP was carried out. The final result is shown in Figure 16.

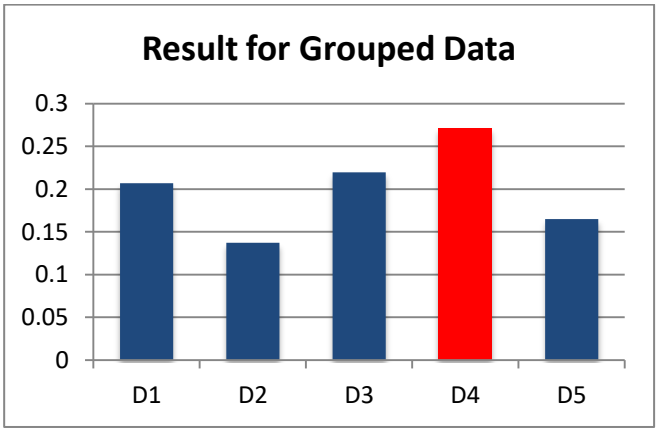

Figure 17: Result for grouped data

From the result achieved through the calculations, it shows that Design 4 which is 0.2707 having the highest score after being compared towards other design. Design 4 has the high accuracy checking due to the pin attach and inserted in the insert of the seal, low ease of use due to takes time in order to properly place the pin according to the insert. Design 4 shows the moderate level of maintenance due to the proper care of the pin on the cube for it may disturb the accuracy or the sensor if the metal pin is pressed to hard. In term of longevity, it is low but for flexibility is the most flexible compared to the others because of the yellow cube shown from the design is easily moved about fix according to mat distance.

E. Conclusion

To conclude from this chapter, there are four components carried out which are HOQ, AHP Consistency Ration and discussion between the components. From HOQ, based from the computation, important criteria which will be carried forward to Analytical Hierarchy Process (AHP) are flexibility, ease of maintenance, ease of use, longevity of jig usage and flexibility. These five criterions are selected due to the high weight portion. Once obtain the five main criterions, these criteria will further use in AHP computation for five consecutive times. The result obtain after AHP computation are Design 1 with 20.7%, Design 2 with 13.7%, Design 3 with 22%, Design 4 with 27.1% and Design 5 with 16.5%. Design 4 is selected due to the highest weightage after computation.

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