Designing Modular Fixture for Automotive Condenser Inspection

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การออกแบบอุปกรณ์ยึดจับชนิดหน่วยแยกสำหรับการตรวจสอบเครื่องควบแน่นรถยนต์

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ในอุตสาหกรรมการผลิตชิ้นส่วนยานยนต์ ชิ้นส่วนที่ผลิตออกมาจำเป็นต้องมีคุณภาพและมีความแม่นยำตรงตามมาตรฐานที่ถูกกำหนดไว้ โดยอุปกรณ์ยึดจับมักถูกนำมาใช้ในการตรวจสอบขั้นสุดท้ายเพื่อให้บรรลุวัตถุประสงค์ดังกล่าวได้โดยตลอด อย่างไรก็ดี อุปกรณ์ยึดจับเหล่านี้มักมีความเฉพาะเจาะจงสูง และใช้ได้กับเครื่องควบแน่นเพียงรายการเดียวเท่านั้น การเพิ่มรายการสินค้า จึงส่งผลโดยตรงต่อการเพิ่มขึ้นของอุปกรณ์ยึดจับ ตลอดจนปริมาณทรัพยากรที่ต้องใช้ในการผลิตอุปกรณ์ดังกล่าว ซึ่งนับรวมถึงพื้นที่จัดเก็บ และค่าบำรุงรักษาที่สูงอย่างหลีกเลี่ยงไม่ได้ ด้วยเหตุดังกล่าว ผู้วิจัยจึงได้ทำการศึกษา เพื่อค้นหาแนวทางการในการออกแบบอุปกรณ์ยึดจับที่ตอบสนองต่อความต้องการของลูกค้าที่มีความหลากหลาก และความต้องการของบริษัทกรณีศึกษาที่มุ่งเน้นการลดต้นทุนที่เกิดขึ้นจากอุปกรณ์ยึดจับ ทั้งนี้ ผู้วิจัยได้นำเสนอแนวคิดการออกแบบอุปกรณ์ยึดจับชนิดหน่วยแยกแบบหลายระดับต่อบริษัทกรณีศึกษา ผู้วิจัยพบว่า อุปกรณ์ยึดจับแบบ 3 ระดับ ให้ผลลัพธ์ที่ดีที่สุดทั้งในมุมของความยืดหยุ่น ต้นทุน และคุณภาพ โดยอุปกรณ์ยึดจับแบบ 3 ระดับนี้สามารถลดค่าใช้จ่ายที่เกี่ยวเนื่องลงได้กว่า 240,000 บาทต่อปี และช่วยในการประหยัดพื้นที่การจัดเก็บลงได้กว่า 29 ลูกบาศก์เมตรอีกด้วย

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In the automotive component manufacturing industry, the automotive parts must be produced with high precision according to the standard. And, to achieve such a goal, inspection fixtures are typically used as final inspection tools. These fixtures are highly specialized that often match only one stock-keeping unit of the condenser (SKU) each. Based on such a fact, as the number of SKUs rises, the number of fixtures produced would be inevitably increased, along with the resources required for fixture production, storage space, and maintenance. In order to address such issues, we explore and develop a new fixture design that turns specialized fixture into a more flexible one consuming less resources. This new fixture design is based on a modular fixture concept, where various fixture designs are proposed; but, the 3-level one is selected as it provides the best results compared to the rest and the original design. We find that this new design could potentially reduce the production cost by 240,000 Baht per year and save up to 29 cubic meters.

Field of Study:	Industrial Engineering	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....

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Tanest Lertkajornkitti

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

1. Introduction

1.1. Industry Introduction

Thailand has been the hub of the automotive industry of South East Asia since the 1990s and often called "Detroit of the East" by many experts (Asasappakij 2012). In the past few decades, many foreign carmakers had set up factories in Thailand, especially the Japanese automotive makers. With local content regulations, the automotive parts factories soon followed the automotive manufacturers and set up production plants in Thailand to support them. These companies are often direct suppliers to the automotive manufacturers known as "Tier 1" suppliers. The tier 1 suppliers source their materials and parts from local factories and companies, often called the tier 2 and tier 3 suppliers. These factories are a mix of full ownership by the local and joint venture with tier 1 companies.

Thai-owned companies were hoping to get some technological transfer from more advanced Japanese, European, and American companies. However, often time the advanced technologies were kept as a trade secret or under heavy regulation by the holders. In many cases, tier 2 and tier 3 companies rarely gain any technological transfer from the tier 1 companies. Tier 2 and tier 3 companies were sometimes required to rent or purchase the technologies from the tier 1 companies to meet the requirement set by the automotive manufacturers. Soon these tier 2 and tier 3 companies would be entirely dependent on the tier 1 companies.

As Thai’s companies gain a stronger reputation for the high-quality automobile and automotive parts, a new market segment of automotive parts emerges. The aftermarket or replacement market is the market segment that caters to the automobile repair sector. Since the original equipment (OE) are often priced very high due to many factors such as quality, marketing, distribution, research and development, and retail cost. Prior to the emergence of the replacement equipment (RE), the replacement parts were monopolized by the automakers. As more aftermarket parts appear in the market, the consumers have more choices of brand, quality, design, and price. Often time RE parts are cheaper as compared to OE parts, with some exception of high-performance RE parts that are priced higher than OE parts. Some of the best quality aftermarket parts would have similar appearance, performance, and fully compatible with the automobile without modification.

During the post-economic crisis in 1997, many entrepreneurs saw an opportunity in the growing RE parts market. The growth was accelerated by the economic downturn as consumers sought a cheaper alternative to automotive repair in a difficult time. The RE parts market's growth pushes the increase in size and number of automotive manufacturing companies. The majority of these RE parts manufacturers have some past connection with the tier 1 or 2 manufacturers, sometimes as tier 3 or just a small sub-contractor to the tier 1 and 2 companies. Even though they gained some technological transfer while operating as tier 3 suppliers and sub-contractors, as the years pass, these technologies become obsolete. Soon they have to obtain their technology to remain competitive in the market. Due to the nature of the business, technological advances would have to come from in-house research and development. The in-house research and development technologies are closely guarded trade secrets and rarely patented. These technologies then become the source of competitive advantage for many companies.

Kitti Engineering Partnership was set up in 1979, later changed to President Automobile Industries Co., Ltd. in 1986, to product motorcycle parts to supply tier 1 suppliers. As a tier 2 supplier, Kitti Engineering was able to gain technological, network, and market knowledge from this business partnership. In 1986, President Automobile Industries changed the company's direction to produce the RE parts. Today, President Automobile Industries Co., Ltd. under the brand of PACO is one of the six biggest automotive air-conditioning factories in Thailand. PACO is also one of the only two factories in Thailand that produce automotive air-conditioning for the RE market.

From the interview with the CEO, the core competency of PACO is in the engineering practicality of the production method, and tooling. One example is the fixture system that PACO produces. It is practical, low cost, simple, and quick to be produced. This system allows PACO to engineer on average one new model per day. However, this fixture system was an old technology that has not been updated or revised for over 20 years. This design has some disadvantages that were not foreseen 20 years ago. The fixtures require a sustainable amount of space to store, and now

PACO is facing storage problems. The utilization was also very low for various models. However, the fixtures cannot be destroyed because of its business nature as RE producer.

This thesis aims to study and propose a new fixture design that could improve utilization, shorten the engineering time, and reduce the storage space required.

1.2. Problem Statement

The fixtures in the automotive component manufacturing industry are very part specific. The automotive component manufacturing needs precisions to meet the standard, but at the same time, it needs to maintain low production cost with the economies of scale, so the fixtures are often used as a final inspection tool. These fixtures are very part-specific that often match 1 stock keeping unit of the condenser (SKU) per fixture. Each SKU requires at least 1 fixture but could be more depending on the manufacturing techniques.

In the automotive component industry, the OEM tier 1 suppliers need to produce a component for the lifetime of a car model. This lifetime includes the 7 years' production period, 5 years' warranty period, and another 3 to 7 years' repair period. It is very common for a component to be in production for 15 to 20 years. Some car manufacturers would allow those tier 1 companies to handle the repair period at their own cost and profits.

However, this lifetime period is different for RE parts manufactures. The lifetime of the aftermarket parts depends on the function and warranty coverage of that specific part. The components can be categorized into 3 main categories: crash parts, maintenance parts, and repair parts. If the parts were vulnerable to accidents, such as body parts, lamps, radiators, and condensers, they were considered as crash parts. Crash parts would have to be produced as soon as the car model was launched into the market. If the part is normal wear and tear component that requires regular maintenance such as break, filters, and fluids, the RE parts would be considered as maintenance parts. The maintenance parts would usually be launched around 1 year after the car model was launched. If the part was covered under factory warranty such as engine parts, gearbox, and transmission, the part was considered as repair parts. The repair parts were usually launched by the RE manufacturer 3 to 5 years after the car model launched. These components were kept in production for around 20 years or as long as there was a market for it.

Automakers are producing a large number of models to serve all segments of the market and capture the highest market share. Table 1 shows some of the top world brands and the number of models sold globally at present, for the past 10, and 20 years. It is worth noting that the information shown in table 1 is just a small part of the whole automotive component market. In order to capture a broader market, the RE manufacturers continue to increase the number of SKUs to serve all markets.

Table 1 Number of models produced by car manufacturer.

Car Maker	Current model	10 years accumulated	20 years accumulated
BMW	26	43	60
Mercedes-Benz	30	57	79
Toyota	30	57	130
Ford	54	94	169
Chevrolet	71	110	146
Volkswagen	36	71	95

Source (Wikipedia 2016)

As PACO is currently one of the largest RE condenser manufacturers with the largest number of SKUs, PACO's products cover European, Japanese and American car brands serving North America, Asia, Middle East, and Africa market. As mentioned earlier, that automotive component requires precision and economy of scale, to achieve both requirements, PACO uses its own successful flexible manufacturing system.

In condenser manufacturing, the process can be classified into 6 main categories: component production, assembly, brazing, second assembly, quality inspection, and packing (Figure 1).

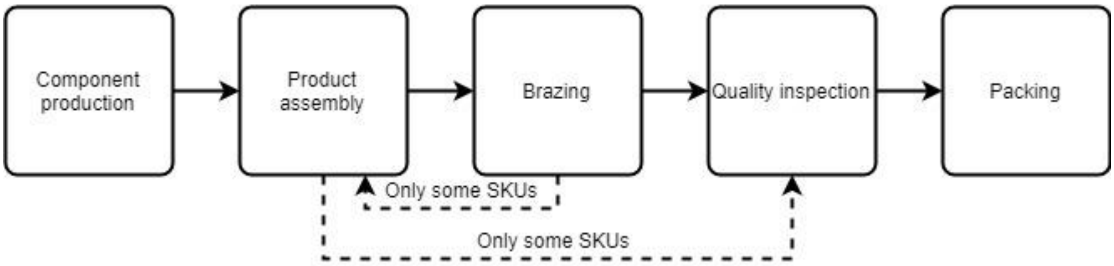


Figure 1 Condenser manufacturing process

The modern condenser consists of tubes, fins, header, inlet, and outlet as standard parts, and some SKUs could also consist of the mounting bracket, integrated drier, and piping. Figure 2 shows all the condensers and the components.

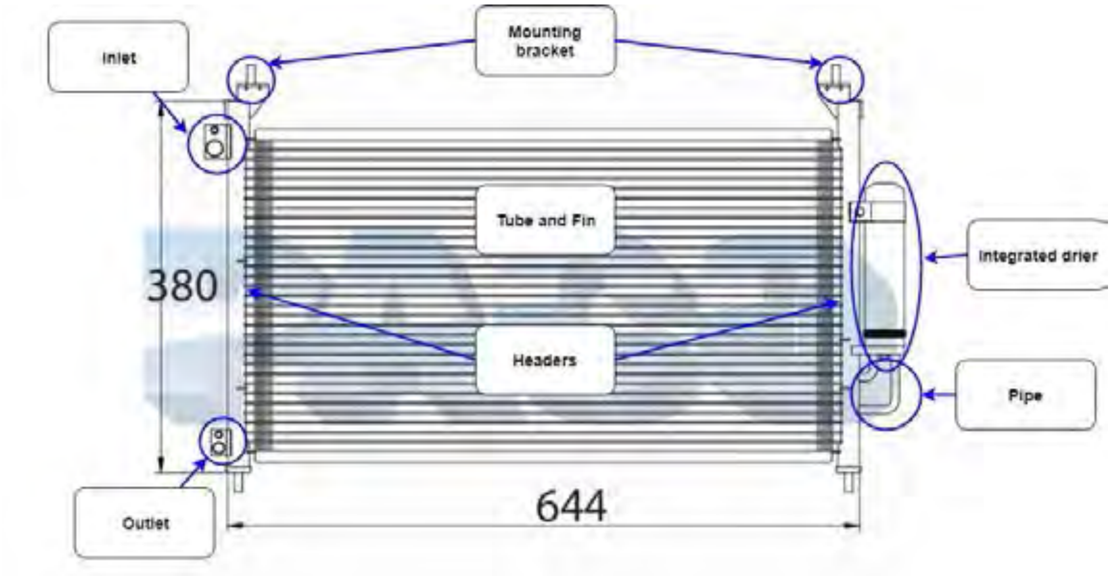


Figure 2 Condenser's components

Most of the component production at PACO are inhouse. Component production processes ran parallel as shown in figure 3. The components then used in the assembly in 2 steps, namely core assembly and first accessories assembly. During the core assembly, the tubes, fins, and headers were assembled to form the body of the condensers. Then some accessories that do not heat sensitive such as inlet, outlet, and some mounting bracket were assembled during this step. The brazing process joins all components together. If the SKUs require extra assembly, it was done after the brazing process. The final inspection requires 2 steps. Firstly, all parts go through the critical point inspections. Then a performance quality check was done before packing the parts into the box.

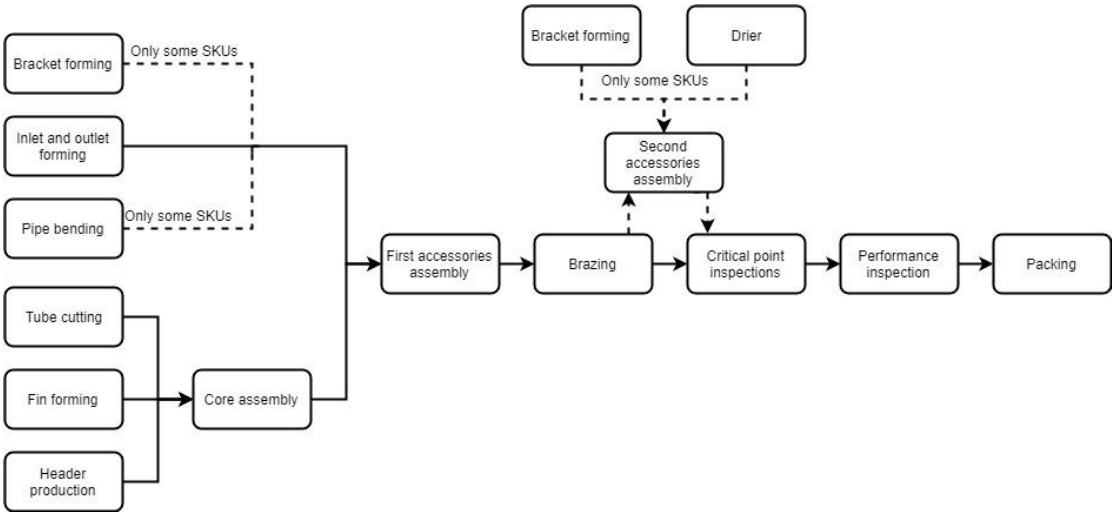


Figure 3 Detailed PACO's manufacturing process

PACO's fixture system was used to check for critical measurements at a quick speed. The fixture system in Figure 44 and **Error! Reference source not found.**5 was one of the company's core competencies during the interview with the CEO. He also mentioned some significant concerns regarding this fixture system. Since the current fixture design was very SKU specific, this resulted in low utilization as each fixture was designed for a single specific model.

Figure 4 Current fixture at PACO with workpiece

Figure 5 Current fixture at PACO without workpiece

This problem was an essential problem for the company and to prevent this project from being a sacred cow project, the key stakeholders would have to be identified (Oréal 2015). Table 2 shows all key stakeholders of the fixture problem, and also, the pain points that those stakeholders were facing possible future problems.

Table 2 Pain points of stakeholders

Key Stakeholder	Pain points	Possible future problem
Owners and Shareholders	The fixtures were a sunk cost asset with high risk in specific models	With such a sunk cost asset, the company requires constant asset investment. There was little benefit for additional SKUs that carry a high risk
Management team	The fixture was one of the core competencies of the company that have not been updated since the 1990s	The company enjoyed many years of competitive advantage because of the fixture system. However, the competition was catching up in terms of the number of SKUs, low cost, and quick prototyping. Without updating the fixture systems, the company risks losing this competitive advantage.

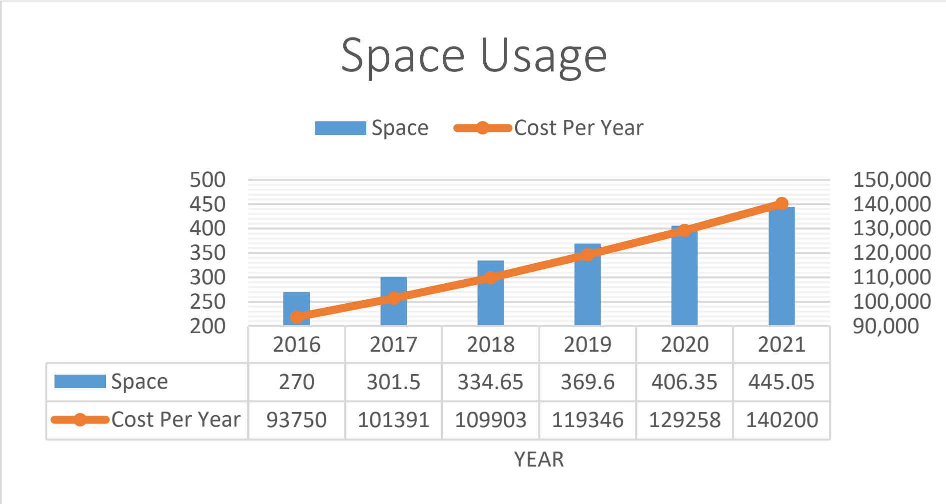
Table 2 Pain points of stakeholders

Key Stakeholder	Pain points	Possible future problem
Sales and Marketing team	Even though PACO was one of the fastest companies to launch a new model, the growth of the number of models was exceeding its capacity.	Competitors could enter the market in the model segments that PACO could not cover due to the slowness of launching a new model.
Product Development team	Each fixture requires a new build up from scratch. Hence the launch process could not further be streamlined.	The only way to increase product launch was to increase the team size, which was an inefficient solution.
Production team	The fixture storage space at the moment was reaching full capacity.	As the SKUs expand, the production team would need to seek space to store the increased number of fixtures. Which at this moment such space was not available.

Table 2 Pain points of stakeholders

Key Stakeholder	Pain points	Possible future problem
Quality team	The fixture storage system was not up to the quality standard, but this was due to the lack of space.	As the space problem grows, more fixtures were at risk of not meeting the quality standard.
Finance and Accounting team	Fixtures were assets that could not be included in the cost of goods sold. However, since the fixture was very SKUs specific, it was affecting directly to the production cost. In terms of accounting, the cost does not be accurately reflecting the actual cost; hence the actual cost of each SKUs was not correctly communicated to other stakeholders.	No real concern.

The pain points from the stakeholders point to 3 significant concerns, namely the storage space, cost, and launch timeline. The magnitude of these concerns could be calculated from simple calculations and estimations. With more than 1,800 SKUs of condensers and increases at the rapid rate of 200 SKUs per year, as PACO expands its' range of products, this creates a storage area problem. Each fixture requires a storage space of around 100 cm by 50 cm by 30 cm or 0.15 m3 of storage space per fixture. With the current number of fixtures, they were using around 270 m3 space for storage. By 2021 PACO would needs around 445m3 storage space. This can be converted to land area assuming the maximum height to the storage of 3 meters. Figure 6 summarizes the space requirement. They were currently storing the fixtures along the wall of the factory which has limited space for future expansion. Due to the nature of this business and the company's policy, the fixtures could not be destroyed or disposed of. Eventually, the storage space requires expansion. Figure 6 summarized the expansion cost. The cost was estimated from the land cost at around 5 million baht per rai, with an increase of 3% per year. By 2021, PACO will have to spend around 140,000 baht on just land area to accommodate the new fixtures



	2016	2017	2018	2019	2020	2021
Space	270	301.5	334.65	369.6	406.35	445.05
Cost Per Year	93750	101391	109903	119346	129258	140200

Figure 6 Space and Cost increase for fixture storage

Creating an expensive fixture system was not desirable since one of the company's core competency is the fast and low-cost fixture system. Currently, each fixture would require an average of 30 working days to be designed and produced. Each fixture cost at an average of 2,000 baht with no salvage cost at the end of its lifetime. The new fixture has to solve the pain points and prevent future problems raised by the stakeholders. A new fixture system has to be easy for design, low cost, accurate, easy to use, save space, and quick to be manufactured.

1.3. Research Objective

The thesis aims to provide a new fixture design, together with the guidelines for choosing the suitable fixture design for product inspections that helps reduce the increasing storage space problem for inspection fixtures. The trade-offs also take into account to provide the optimal design for mass production usage.

1.4. Research Scope

There are many condensers design in the market at this moment, to allow a more precise definition of the models of the product that be included in this research only limited scoop was set. Firstly, only the tube-type plate-fin parallel flow condenser would be considered (Shah and Sekulic 2003). However, due to a large number of such designs, the 105 latest models at PACO were the highest priority models to be considered.

From the selected brands, a handful of models was selected based on the model platform, size, and production year. Honda and Nissan use a pin mounting design in almost all of the models; hence, these 2 brands will benefit significantly from the modular fixture design.

2. Literature Review

The research to solve a manufacturing process was not straightforward. In order to effectively propose the best solution for the company's fixture problem all of the possible impact factors were studied. These factors included business, financial and engineering factors. This literature review provides all the current aspects of business impact, trade-offs, inspection process, fixture design, modular fixture, and cost calculation.

2.1. Business Impact

The current common method of optimization or improvement at the small company was based purely on experience, intuition, or a sacred cow project. However, to truly make any project the highest impact project, it was essential to look at various business aspects. According to the Crafting and Executing Strategy book, the most critical part of any business strategy was to have a competitive advantage (Thompson, Peteraf et al. 2015). These competitive advantages are created from the core competency of the company (Oréal 2015). The core competency is any knowledge or capacities of a company over the competitors that are hard to replicate (Thompson, Peteraf et al. 2015).

According to Ansoff Matrix seem in figure 7, there are four areas of strategy planning, namely: Market Penetration, Product Development, Market Development, and Diversification (Thompson, Peteraf et al. 2015).

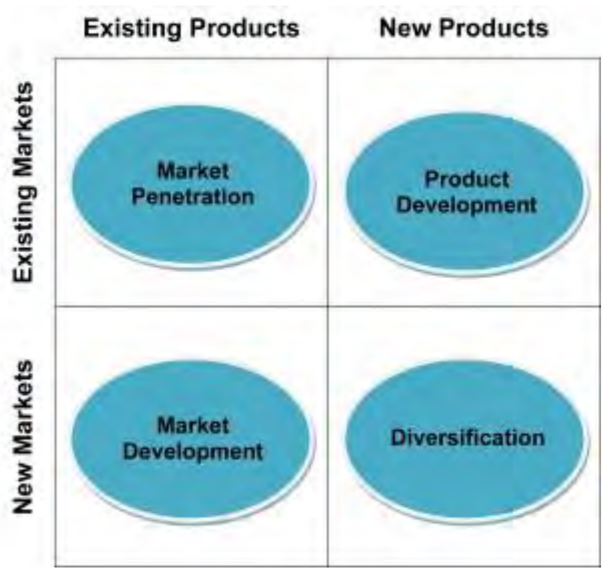


Figure 7 Ansoff Matrix

According to Professor Serge O'real, the most fundamental step that any company have to do in any strategic planning is to optimize the current product in the current market to increase market penetration (Oréal 2015). Hence, the focus should be on the optimization of the current products.

2.2. Trade-offs

All designers will have to face the decision of specialization or flexibility. In other aspects, this will affect the performance and robustness of the design. Frequently, maximization of the performance and increase of the robustness are two conflicting objectives, which means that a trade-off exists between robustness and performance. Since there was only one solution, the optimization of the trade-off was needed. The optimization of the trade-off was, and that can be done by performance optimization (Yaochu Jin 2003).

In the case of a modular fixture, there was a trade-off for having a more flexible design. The higher the flexibility, the more complex the design will be, this will result in longer design time, manufacturing time and setup time and this implies that the cost was higher for a more flexible design. For every trade-off, a lost in one factor will result in a gain in another factor. Therefore, a balance between the desired gain and the acceptable lost have to be made for the optimized design.

2.3. Inspection Process

The inspection of the product is an essential process for any company. If the product was not given a proper inspection, there could be a large monetary effect. Quality control is split into three primary steps: Pre-production, during production, and pre-shipment. The potential monetary effect of defective parts is estimated to increase by ten times for each step that it was not detected (qualityinspection.org 2019).

The Pre-production inspection is carried out before the start of production processes. This process involves the inspection of raw material and components. These components could originate from the purchase or internal production from the previous production process. This inspection focuses on the component conformity with the specification and quantity ordered.

The during production inspection is carried out during production processes. This inspection is especially useful for controlling the strict specification and quantity in a continuous production process. Since the during process inspection is dynamic and is a quality control inspection conducted while production is underway so the result from the inspection could be used to make micro-adjustments to keep the product within tolerance and reduce the number overproduction.

The Pre-shipment inspection, also often known as final inspection, is one of the most crucial inspection processes for quality control. This is the final step before the product reaches the consumer; hence if any defect goes through this step, there could have a tremendous impact. Depending on the product, some require only sampling inspection but would require 100% inspection (HQTS 2019). The right inspection process has to be identified to yield the correct design that would meet the inspection requirements.

2.4. Fixture Design

A fixture is defined as a mechanism used in manufacturing to hold a workpiece, position it correctly with respect to a machine tool, and support it during machining (Cecil 2001). It can be considered as a component of machine-tool installations, specially designed in each case, to position the workpiece, hold it firmly in place, and guide the motion of power tool (Abouhenidi 2014). A fixture is a device that secures a single object or multiple objects to a location in space relative to a specific reference plane and points by limiting at least four of its possible six degrees of movement in space (Rockler 2008). In many applications, fixtures were used during the machining process, assembly, and transportation. However, there were limited studies in the inspection. Therefore, each component of a standard fixture and its' functions have to be understood before designing the fixture.

A fixture usually consists of 4 main components: the base, pillar or raiser, clamp, and guide.

1. The bases were usually made of solid materials which were mild steel, and more recently, the aluminum (Kundu 2014) (Kinto). The rationale behind this design was lightness.

2. The pillar and raiser were the components used to give the fixture more 3-dimension flexibility. This component connects between the base and the clamp and guide. These were usually welded or fixed permanently for stability. Pillars have to have minimum flexibility during use for the highest accuracy (Kinto).

3. Clamps were the component used to hold down the workpiece while it is being worked. Clamps were more often found in fixtures used in machining and transporting process, but it is unnecessary in inspection fixtures.

4. Guides were the component used to guide the workpiece into a proper position for clamping or inspection. Guides were a more often used component in inspection fixtures.

The fixtures design process was generalized into five basic steps (Pachbhai and Raut 2014).

1. Defining Requirements

   The requirements were made from the researchers and the user of the fixture. Since the requirements could be unique to each user and environments, the requirement should be from the direct stakeholders of the fixture. These requirements must be well defined and concrete.

2. Gathering and Analyzing Information

   The gathering of information will be done onsite or by calculation. The information gathered should coincide with the defined requirements.

3. Developing Several Options

   There should be several options to explore and compared. Certain design flaw might not be discovered from the data gathered

4. Choosing the Best Option

   From the design options, the best option will be the fixture system with the best result that met the requirements. This option should also yield better results comparing to the existing design.

5. Implementing the Design

   The design has to be implemented with a clear implementation plans and timeline. The implementation plans must cover all aspect of operations under normal circumstances.

The fixed fixture design is the very basic type of fixture that was widely used. Fixed fixtures have advantages such as low cost, easy to design, rigid, and easy to manufactured. The alternative to a fixed fixture is the flexible fixture or modular fixtures.

2.5. Modular Fixture

The modular fixture was not a new idea with many industries adapting to this. The modular fixture would have parts that were interchangeable to allow it to be used in multiple situations (Hong 2007). These parts would be CNC machined from mild steel due to cost (Kundu 2014). This fixture should be simple, lightweight, and cheap. The purpose of the fixture has to maintain or improve the function of the current fixture, namely productivity, interchangeability, skill reduction, and cost reduction (Mansor 2010). Modular fixtures, as shown in figure 8, are often used in prototyping or one-time manufacturing because of the configurability. Recently, modular fixtures were adapted to be used in large structure assembly such as in aircraft assembly. However, it was rare to be used for small, mass-produced products due to the complexity of the design and the setup process

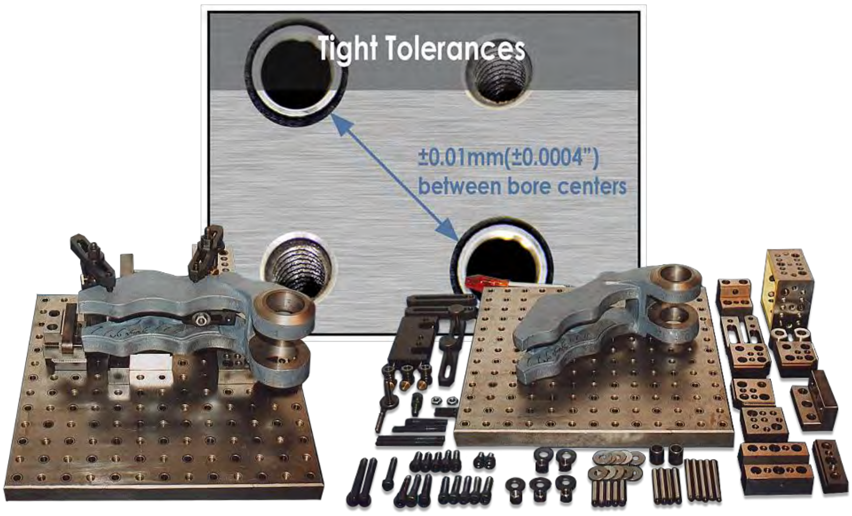


Figure 8 Off the shelf modular fixture system (Fixturing)

Modular fixtures are similar to any fixtures. The base of a modular fixture is a grid plate or T-slot plate type for 2-dimensions fixture. Similar to other fixtures, the addition of riser block, tooling column, and plate creates a 3-dimensions fixture. These fixtures would depend on the glide and clamp system that holds the workpiece down (Fixtureworks). However, the universal modular fixture and fixture system are usually expensive and too universal for a specialized industry that requires a low-cost fixture. In a specialized industry, a custom-made system is required, which further increases the cost of the system. In a low to the medium volume production plant, the flexibility of modular fixture is desired; but, there were no economical methods to meet such demand (Gmeiner 2015).

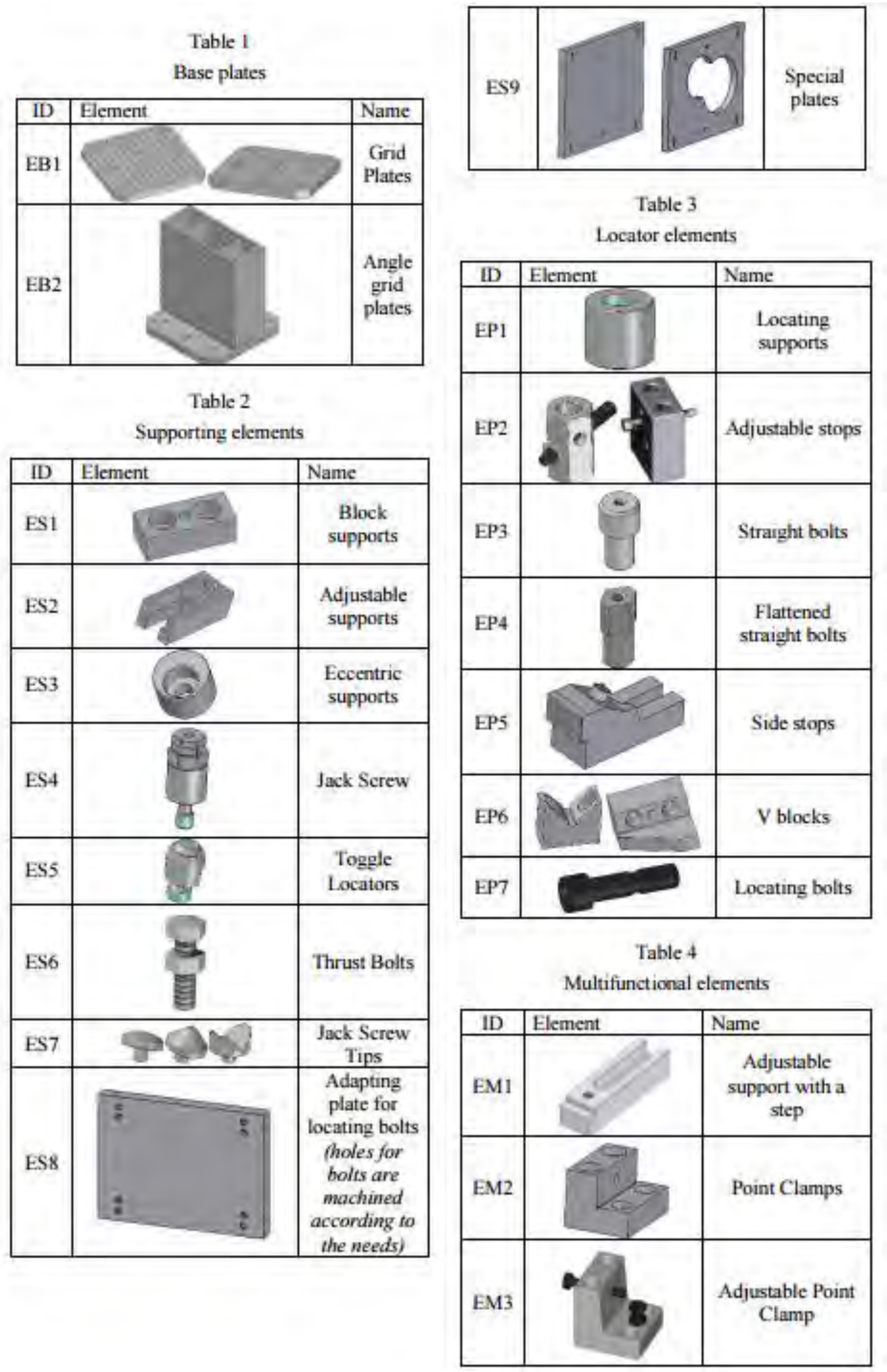


Table 1
Base plates

ID	Element	Name
EB1		Grid Plates
EB2		Angle grid plates

Table 2
Supporting elements

ID	Element	Name
ES1		Block supports
ES2		Adjustable supports
ES3		Eccentric supports
ES4		Jack Screw
ES5		Toggle Locators
ES6		Thrust Bolts
ES7		Jack Screw Tips
ES8		Adapting plate for locating bolts *(holes for bolts are machined according to the needs)*
ES9		Special plates

Table 3
Locator elements

ID	Element	Name
EP1		Locating supports
EP2		Adjustable stops
EP3		Straight bolts
EP4		Flattened straight bolts
EP5		Side stops
EP6		V blocks
EP7		Locating bolts

Table 4
Multifunctional elements

ID	Element	Name
EM1		Adjustable support with a step
EM2		Point Clamps
EM3		Adjustable Point Clamp

Figure 9 Break down of component of modular fixture system (Rétfalvi and Stampfer 2013)

The new recent development of the Affordable Reconfigurable Fixture (ART) shown in figure 10 is a Box Joint system that allows cheaper conversion of old structure into modular structures (Helgosson, Ossbahr et al. 2010). However, this is more suitable for the large frame structure fixture such as fixture for automotive body or aircraft wings. The Box Joint system is easy to design but requires skills to assemble. This hint to the next problem with the modular fixture, the difficulty of design and assembly.

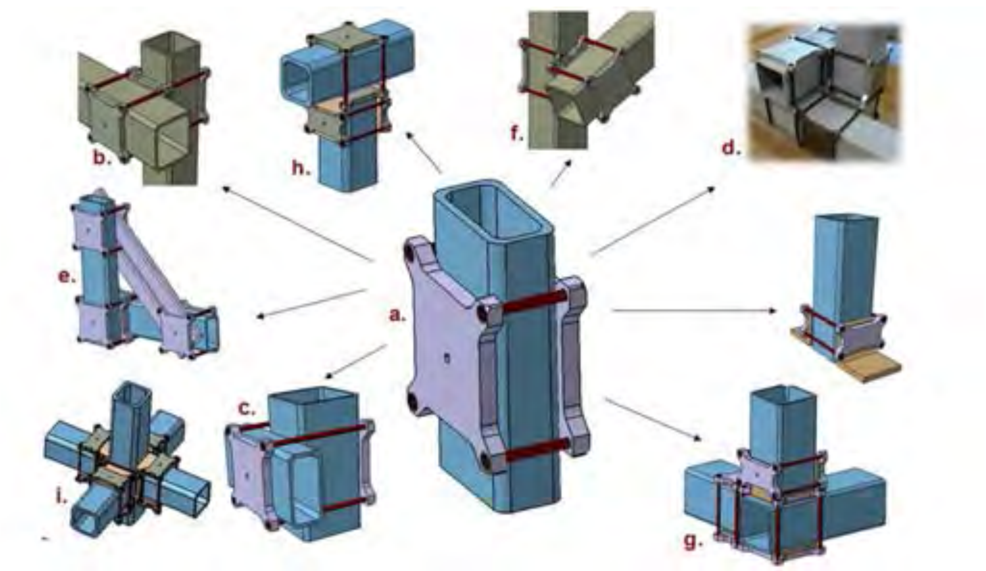


Figure 10 Box Joint system (Helgosson, Ossbahr et al. 2010)

The current study focuses on using the computer to aid in the designing of modular fixtures. This is due to the complexity of designing a modular fixture that yields high flexibility (Ann 1990). The usual methods of designing the fixtures were based on computer-aids or experience which required large accumulated knowledge and experience in fixture design (Gmeiner 2015). In recent studies, the elements of the modular fixtures have been categorized into some basic categories as the fixed fixtures namely the Base, Supporting, Locator and multifunction components to allow the computer to judge the right component use (Rétfalvi and Stampfer 2013).

Another great advantage of a fixed fixture over the modular fixture is the tolerances. The fixtures have various tolerances depending on the fixture stiffness, deformability, elasticity, and workpiece characteristic. The two methods used to determine the tolerances were finite element analysis method and analytic approach. Most companies would resort to high stiffness fixtures to avoid such tolerances (Zheng 2005). Using the FEA method would take further research into the fixture design.

Since modular fixtures were often associated with high cost, it was crucial that the new design's cost of the fixture was thoroughly calculated.

2.6. Cost Calculation

It was identified in the stakeholder pain points that the cost of fixtures was a fixed asset with no salvage cost. In the current design, the cost was easily calculated since each SKUs required a fixture. However, this means that over time, this cost per unit of a new model does not decrease. The new design should solve this accumulated cost problem. To evaluate the cost of fixture correctly, each component and steps of fixture manufacturing and operation have to be studied.

There are many ways to calculate the cost of production and the cost of operation. The simplest way to categorized costs was to categorize them into direct labor, raw materials, and overhead costs (Monteiro 2001). Direct labor and raw material costs were easy to calculate. However, for the case of overhead costs, it is more difficult to define, especially in a single process of production. The overhead cost is usually estimated from the total cost of production, taking out the direct labor and raw material cost. Usually, this would end up with higher overhead costs than actually giving the management wrong information regarding the cost (Brinke 2002). One of the better ways of finding the overall cost is Activity-Based Costing. This is the estimate of the cost per unit output using a smaller sample size (Miller 1995). Cooper broke down these costs in a more detailed level, as shown in figure 11 (Brinke 2002).

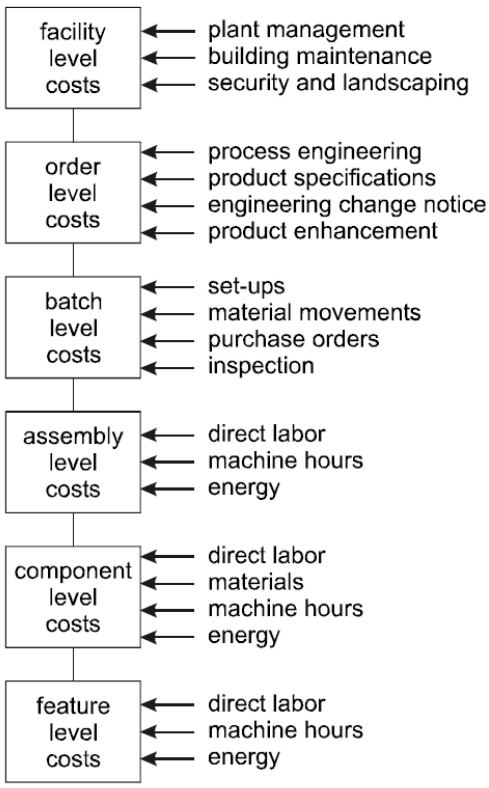


Figure 11 Cost break down table

2.7. Development from Literature Reviews

This research focused on the improvement of the final inspection process of the company. Many paper and thesis provide the generalize process of the research and designing a suitable fixture, however it is not specific enough the condenser inspection process. With the guideline on the design processes, the element of modular fixture and cost calculation more proper research was derived from providing the best solution.

3. Methodology of Research

This research was separated into two main parts, namely the analysis, and the proposed solution.

The analysis consisted of defining the requirements, gathering the relevant data, and analyzing the data collected.

The proposed solution consisted of multiple fixture designs derived from the analysis.

3.1. Design Process

The standard 5 steps design process was adapted to this research's goal. This adaptation provided a better guideline for the design process that would provide the best solution for the improvement of the current fixture problems.

1. Defining Requirements

   The requirements were stated in the problem statements and also from the company's requirement.

2. Gathering and Analyzing Information

   The gathering of information was done onsite collecting the most current information possible.

3. Developing Several Options

   With the limitation of time and resources, developing several options was not likely, but at least three designs would be created with a modular design.

4. Choosing the Best Option

From the three designs, the best option will be the fixture system with the best result comparing to the original benchmark.

5. Implementing the Design

This thesis does not cover the implementation of the new design, but implementation would be done between the researcher and the company during and after the research.

3.1.1.Defining Requirements and Benchmarks

The benchmark would be set from the data collected. The critical benchmarks were obtained from the company's requirements. The benchmarks were:

1. Cost of fixture production.
2. Cost of fixture operation.
3. Time of fixture production.
4. Time of fixture setup.
5. Time of fixture operation.
6. Space for fixture storages.

However, some requirements were none quantitative measurements. Such requirements were difficult to measure and base on personal opinion. Some other requirements were not possible to measure in a short period of time, including ease of design, lifecycle, and common usage. To obtain these benchmarks, the data would be collected at the PACO's factory.

3.1.2.Data Gathering and Analysis

Collecting population data at PACO was impossible in a short period of time. Currently, they have over 1,800 SKUs of condensers 1,800 SKUs, many of the SKUs will only be produced once a year. Due to the large number of SKUs and limited information within the company's database, only certain SKUs would be considered. The focus will only be on the condensers, which requires a fixture for final fitting inspection. The 105 newest SKUs were used as the data set for this research.

Firstly the 105 SKUs were separated into different automotive maker brands to explore the different designs each automotive maker used efficiently. From the 105 SKUs, the total number of design type was found to be 75 variations. These design type determined the number of new gages set that have to be produced for each new SKUs. From the data except for Honda and Nissan, most new SKUs will require a new set of gages. From the data of Mitsubishi, Toyota, and Ford, it was possible to assume that on average, 80% of new SKUs regardless of the automotive maker will require a new SKU. However, the best scenario will be in the automotive maker of Honda and Nissan which have a higher common design, and this resulted in only around 30% to 50% of the new SKUs that will require a new gage set.

Table 3 Number of Design of the latest 105 SKUs

Make	No of Model	Number of Design
Audi	1	1
BMW	1	1
Chevrolet	4	3
Daihatsu	3	2
Ford	8	7
Hino	4	4
Hitachi	1	1
Honda	15	4
Hyundai	4	4
Isuzu	3	3
Jaguar	1	1
Kia	3	2
Mazda	4	2
Mercedes-Benz	4	4
Mini	1	1
Mitsubishi	9	7
Nissan	10	5
Peugeot	1	1

Table 3 Number of Design of the latest 105 SKUs

Make	No of Model	Number of Design
Proton	1	1
Range Rover	2	2
Renault	2	2
Suzuki	4	3
Toyota	19	14

Furthermore, in order to better estimate the number of gages in a set, the number of inspection points for each SKUs were collected. From the data, the mode number of inspection points was 7, while the mean was 8.7 points. Since this modular fixture was designed to be used with all SKUs, the mean number was more suitable to be used as an assumption number of inspection points. As the inspection points have to be an integer, the 8.7 would be rounded up to 9 points for the rest of the research.

Table 4 Inspection points of 105 SKUs.

Inspection points	Number of Parts
6	3
7	47
8	10
9	2
10	16
11	21
12	2
13	3
14	1

3.1.3.Design Analysis

Using the reference from figure 9, the design of the modular fixture will consist of base plates, supporting elements, locator elements, and specialized elements. Each element should complement the function and purpose of the fixtures.

The base plates will become the elements that determine the maximum size of the fixture and will form the working table for this modular fixture design. The possible conventional designs were flat grid plates, angle grid plates, and external frames. The flat grid plates were a flat horizontal surface with holes evenly spread out arranged in a grid pattern. Figure 12 was an example of a type of grid plate. The flat grid plates are commonly used in CNC machines and can quickly be produced or purchased. The angled grid plates are similar to the flat grid plate, except it was usually a vertical surface. The angled grid plates are a flat vertical surface with holes evenly spread out arranged in a grid pattern. Angle grid plates could be used independently or in conjunction with flat grid plates, as shown in figure 13 and 14, respectively. The external frame was rods and joint that forms the outer shell of the working area. The frame could form into a 2-dimensional base frame or 3-dimensional frame, as shown in figure 15 and 16, respectively. The external frame system was commonly used in the Box Joint modular system.

Figure 12 Flat grid plate

Figure 13 Angle grid plate

Figure 14 Flat and angel grid plate

Figure 15 2-dimensional external frame

Figure 16 3-dimensional external frame

Since most of the condensers that will be inspected were 2 dimensional, the base plates should support 2 dimensions and the flat grid, and external frame 2-dimensional base frame will be the most suitable for this function. The external frame system was more flexible than the flat grid in terms of working area size.

However, since these base plates will form the working table, the flat base plate could be more suitable. The base plates element will determine the supporting elements and locator elements. If the external frame was used the supporting elements and locator elements will be the various rods and joints. If the grid plate system was used the supporting elements and locator elements will depend on the functions required. As explored earlier, the rod and joint type system will require skills to assemble and could lead to various problems for PACO. Therefore, the flat grid was more likely to be the better design for this modular fixture.

The support elements and locator elements were used in a similar function that was to give flexibility in different dimensions. The support elements were used to give the fixture a third dimension of height. The locator elements were used to give the fixture more flexibility in the micro-adjustment of the horizontal plane. The problem in designing the support elements and locator elements was the trade-offs between flexibility and ease of setup. Having a more rigid design will give a better performance in terms of setup time, but this would limit the robustness of the design (Yaochu Jin 2003). However, since no research has been done on the exact effect of the trade-offs, this paper will explore this trade-off.

The layering was implemented to explore different incrementation of the fixture. The creation of different incrementations to the fixture has to be done by having holes in the lower layer for the next layer to insert into. If the base layers have 100mm increments for a fixture that has a working space of 500mm by 700mm, there will be a total of 6 holes by 8 holes totaling to 48 holes. If the base layer with the same working space were to have the incrementation of 50mm or 10mm the number of holes will be 165 holes and 3,621 holes respectively. Alternatively, if the smaller increment holes were moved to the upper layer, the number of holes required to be produced will be reduced significantly. A 100mm by 100mm working space upper layer with 10mm increments will require only 121 holes. These smaller upper layers could be moved around to provide the finer incrementation at the required locations. Using the assumption that there were 7 inspection points, the number of holes required will be reduced from 3,621 to only 847 if the 10mm incrementation was moved to the upper layer. The number of holes will be related to the cost of base layer production due to longer machining time. The actual cost of the machining time will be discussed later in Chapter 4.

The holes have a size limitation to be able to install the pin from the next layer. This was specified to be 6mm diameter; hence, the smallest increment possible was 7mm. The requirement of low skill setup pushes us to use a natural number of increments, so 100mm and 10mm were chosen.

If the increment of change for a gage was 100mm, to produce the number of gages with will suit every possible dimension would be 10,000 gages per shape. For 10mm 100 per shape and 1 for 1 mm increment.

Finally, the specialized element, which have the purpose of being the inspection element. These elements are similar to a gage the use to measure the shape and size of the critical inspection points. The gage layer was the layer that has to be produced uniquely for each SKU' design. The gage was not universally shared among all SKUs; however, if 2 SKUs happens to share the same inspection points design, it was possible to share the same gage layer. The possibility of common use of the gage layer depends on the shape, dimension, and distance between each inspection point. It was assumed that the inspection point that requires a different gage must be 1mm different from the existing gage.

3.2. Proposed Solution

The new fixture system will have to be easy to design, low cost, accurate, easy to use, save space, and quick to be manufactured. One of the ways to save space was to use common parts. Currently, each fixture was fixed and the fixtures could not be dissembled in any form. The possible solution was to design a fixture that could be break down for storage. To increase the space saving, the fixtures would have to share a common base. Since the base takes up large space with almost no function during operation. The new design would utilize the working table as the base of the fixture while other critical dimensions will be in a form of different blocks. The block would be unique to each model for ease of design and usage. However, this could incur more cost in manufacturing. But as previously shown, the car manufacturers are increasing their number of models to cover as many segments of the market as possible. The car manufacturers are using common parts for similar models to reduce the number of SKUs and stock required. The new trend of design in automotive component was to use even more common parts. Some sub components and raw material are being designed to be used in multiple SKUs. In condenser production, this was not a new practice. Many manufacturers had already standardized the inlet and outlet ports. In recent new model releases, some condensers are using the same mounting brackets. The common parts designs allow component manufacturer to utilize the same machineries and molds. This will also enable the new fixture design to use a common block hence further reducing the cost of fixture production in subsequent models.

From the research and criteria, 3 designs will be drafted and produced. All 3 designs will use different layers to assist in location adjustments, 4 layers was designed namely Base 100mm layer (Figure 17), 10mm layer (Figure 18), 1mm location spacer (Figure 19 and Figure 20), and the gage block (Figure 21 and Figure 22). The base plate was a flat grid plate with holes that were 100mm apart arranged in grid form. The 10mm layer was second layer will work as locator element with better flexibility as compared to the 100mm layer. The 10mm layer will be used in 3 and 4 level design to explore the effect of an increase in flexibility. The second layer was an adaptation of grid plate design but with a smaller spacing between each hole of 10mm. The 1mm location spacer will be the third layer, the spacer was designed to work as locator element. The spacer will give the modular fixture the highest flexibility to determine the effect of having highly robust design. Only the 4-level design will use the spacer. Lastly, the gage block was a specialize element that use for making the inspection and will also be used as support element if required. This element will be used to do the inspection of the critical point of the condenser parts. The gage block varies in shape and size with each inspection point and would only be commonly used if the inspection point has the same shape and size.

The Base plate that have holes that were 100mm apart will results in 100mm change increment of upper layer for each adjustment. This was same as 10mm layer that will have 10mm holes increment that will result in 10mm adjustment to the upper layer. The 1mm spacer was different as 1mm was very small movement it was nearly impossible to have 1mm holes increment, therefore each spacer be at a specific measurement between 1 to 10 mm from origin as shown in figure 19 and 20. To make the spacer able to make adjustment to height and work as support element a step plate will be needed to give flexibility to height adjustments. The top gage block was the block that will have specific shape was uses to check the work piece. A special top gage block was needed for the 2-level design.

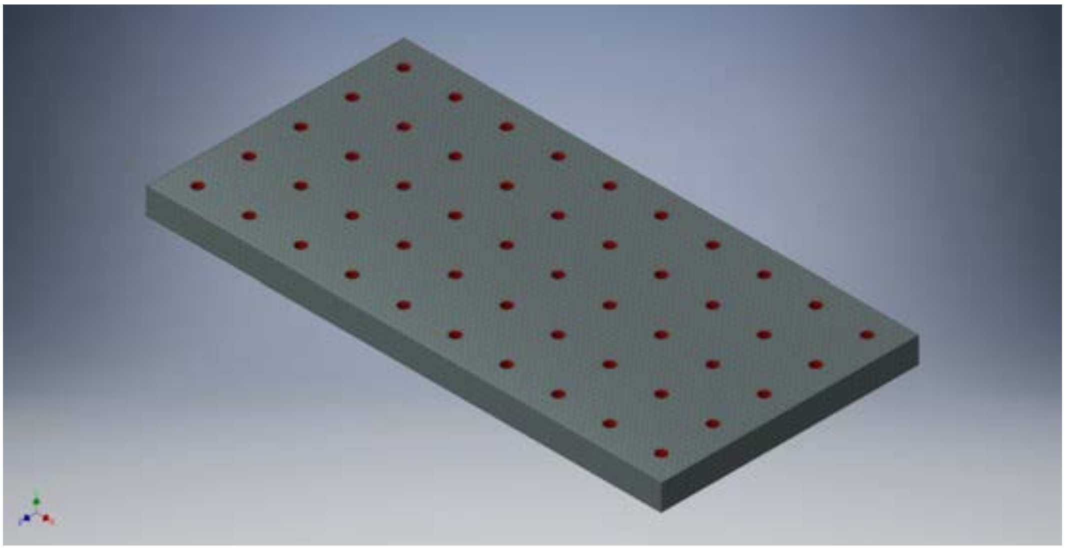


Figure 17 Base 100mm plate

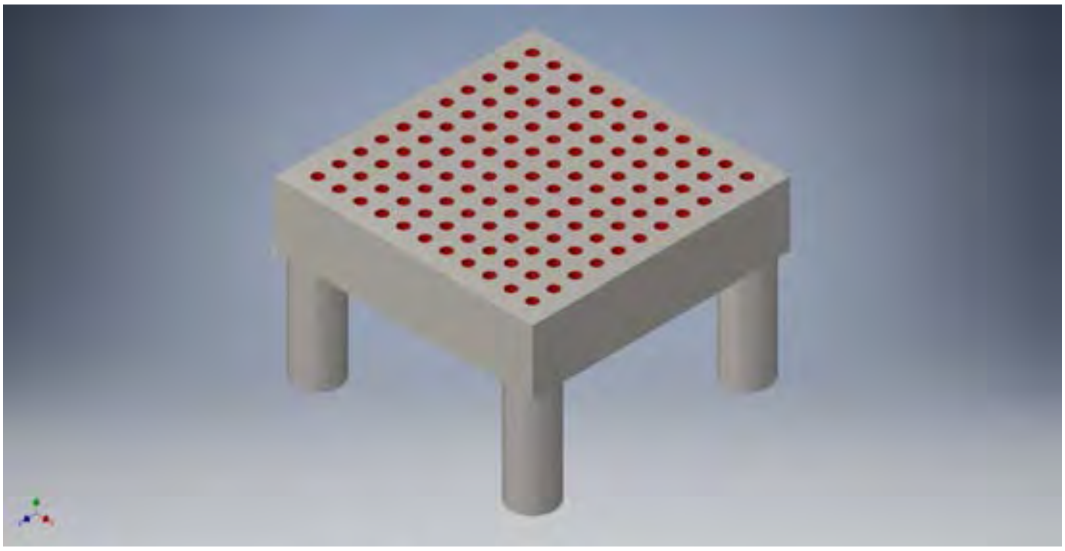


Figure 18 10mm layer

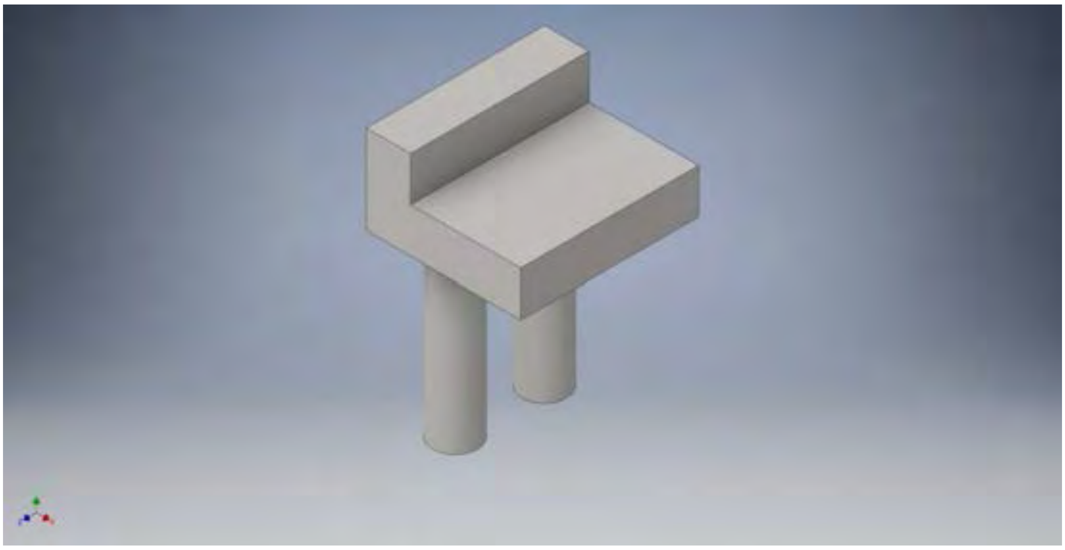


Figure 19 0mm spacer

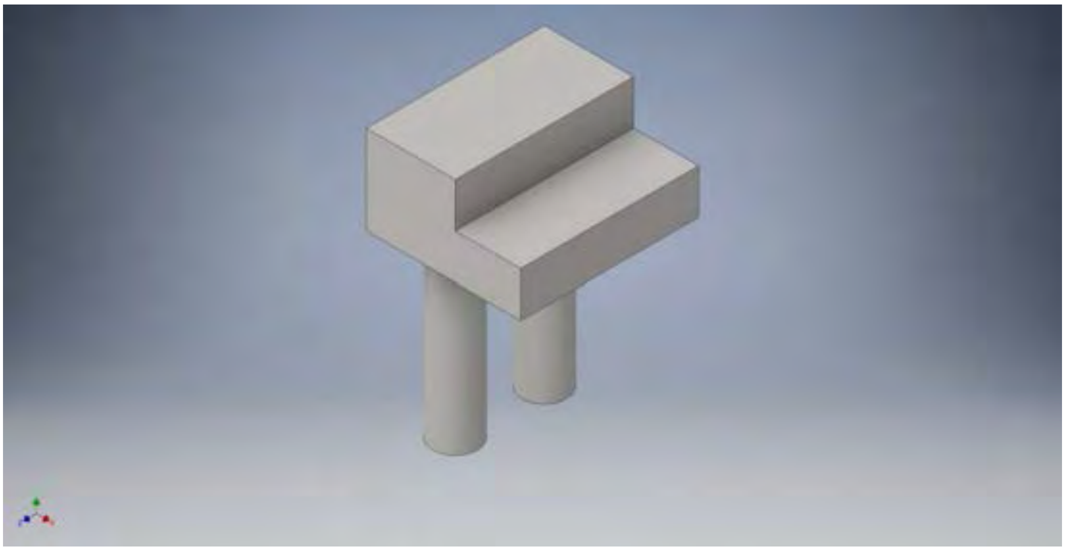


Figure 20 5mm spacer

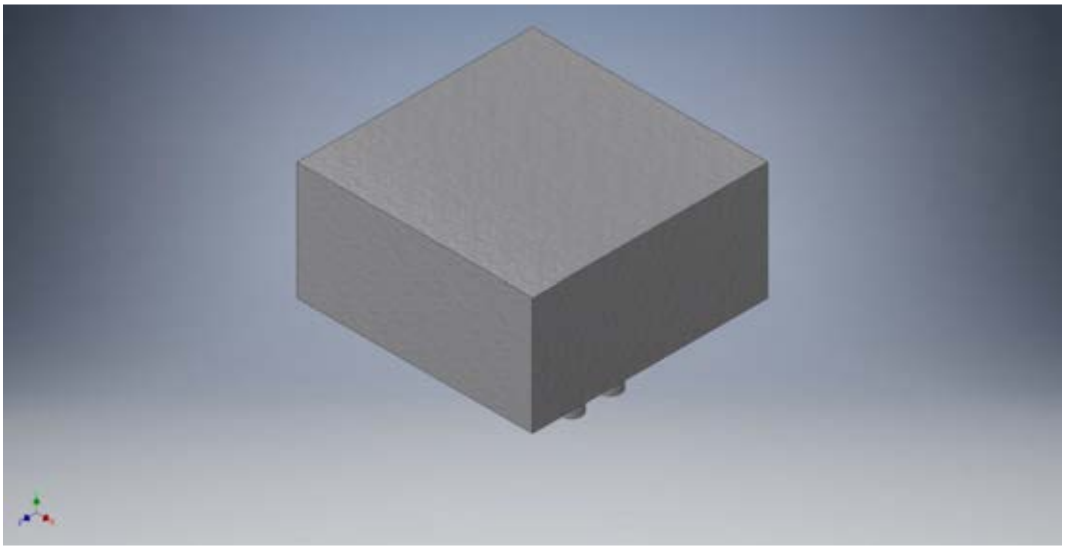


Figure 21 Gage block

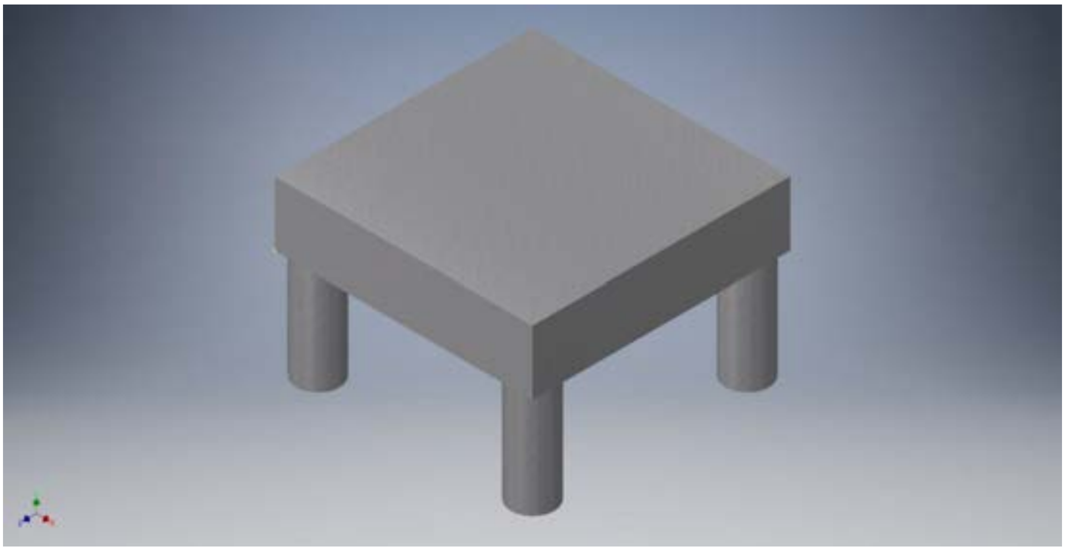


Figure 22 Gage block for 2 Level design

3.2.1.4 Level design

4 level design consists of 4 layers, namely: Base layer, 10mm layer, 1mm location spacer, and gage layer. Each layer will have the same inclement with a stepping ratio of 1:10 for each layer. The 1mm spacer will scale the final layer. The assembled fixture will be similar to figure 23.

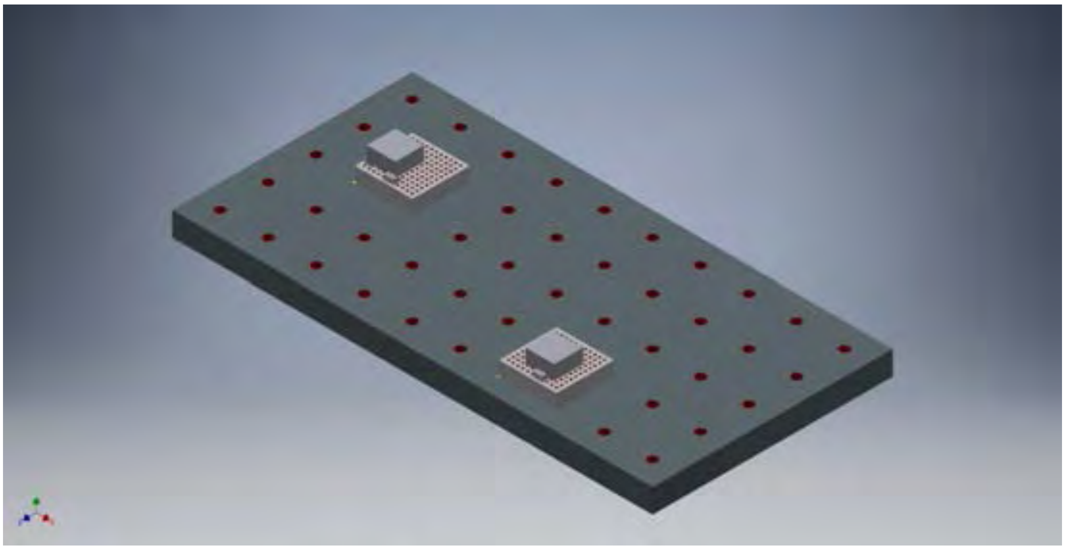


Figure 23 4 Level design

3.2.2.3 Level design

3 Level design was similar to 4 level design; however, the last layer does not have the scaling, but instead, the last layer will be made specifically with each model. This last layer gage block will not be as flexible as in the 4 level design fixtures since the gage block will have a 10mm movement as the smallest increment. The assembled fixture will be similar to figure 24.

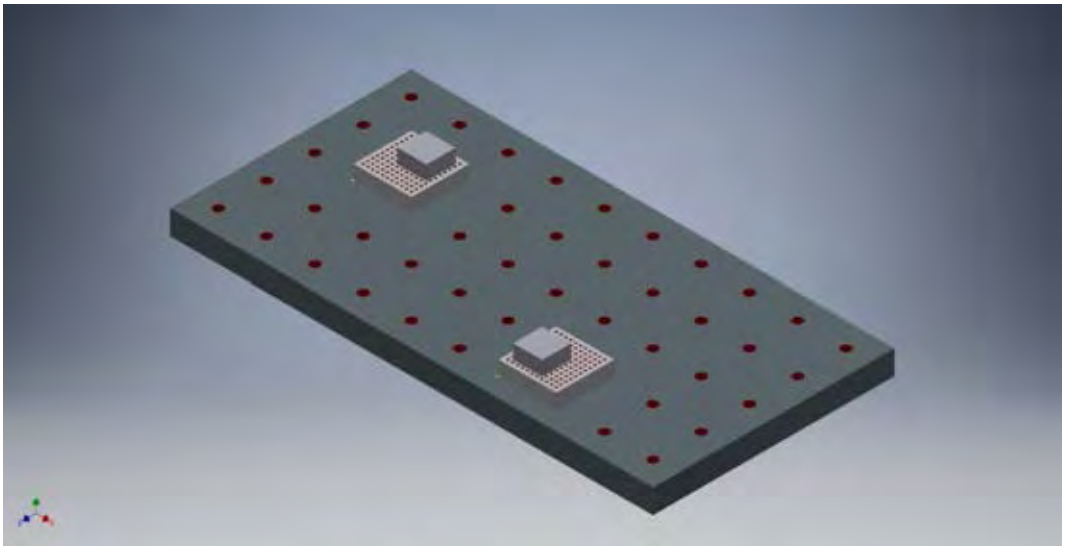


Figure 24 3 Level design

3.2.3.2 Level design

2 Level design type of fixture was a modification of the original fixture. The change was in using a common base. The block mounting on the base layer was made specifically to each model. Hence, the usage of common parts will be low, but the space-saving was done by removing the base. The assembled fixture will be similar to figure 25.

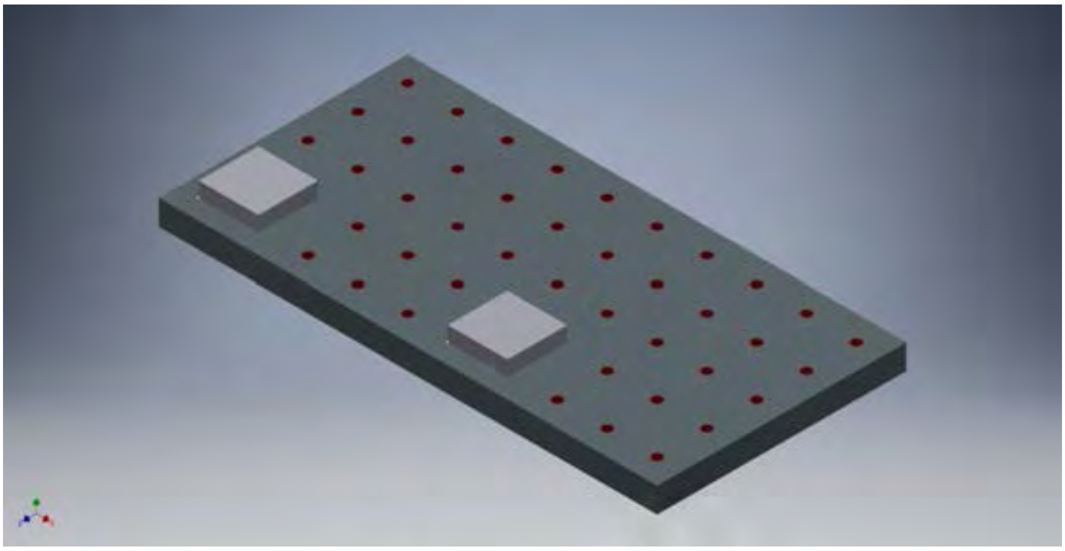


Figure 25 2 Level design

3.3. Comparison of the proposed solution

Table 5 compared the difference between the 3 proposed designs. The 4 level design provided the highest number of shared common parts with the lower increment while the 2 level design provided the lowest number of shared common parts with the largest increment of 100mm. The 3 designs provided adequate variations in the shared common parts and increments to allow further study in the critical factors and trade-offs.

Table 5 Comparison of each fixture design.

Fixture Design	Shared Common Parts	Unique Part	Increments
Original	None	Whole Fixture	None
4 Level	Base 100mm plate, 10mm layer, spacer	Some gage set	1mm
3 Level	Base 100mm plate, 10mm layer	Gage set	10mm
2 Level	Base 100mm plate	Gage set	100mm

3.4. Result Measurement

The data collected from the 3 designs would be used to compare with the initial benchmark. In this research, the critical criteria of study were storage space, launch timeline, and long-term cost saving. However, other benchmarks should also be considered, such as the cost of production, utilization, quality, and ease of use. The result would be both simulated and collected. The data would be validated using a statistical method. Each benchmark would be measured and compared. Hypothesis testing will be done on all quantitative benchmarks. If the outcome shows desirable results, then a conclusion could have arrived. From the research, adjustments, and results, a solution will be proposed to the company.

The result from data collection and comparison will be used to decide on a suitable suggested design for the automotive condenser inspection process.

4. Testing and Data Collection

This thesis does not only aim at single product application results. However, to able to test and prove the concept of a modular fixture for mass production, a single product has to be used as a test sample. The focus will be to create a standardized methodology for a feasibility study that could cover other types of products. These were the steps taken to collect the relevant data needed for analysis.

1. Collect the current parameters of the existing fixtures

   The main parameters that were considered were stated above; production time and production cost. However, the additional parameter that was critical to individual companies could be added. In the case of PACO, the company requested that storage space was added as a critical parameter.

2. Collect the current parameters of normal operations

   The main parameters were stated above; operation time, setup time, and defect rate. However, the additional parameter that was critical to an individual company could be added.

3. Manufacture a prototype of proposed fixtures

   The main design should remain the same with 3 levels of flexibility. The 2 parts that will have to be designed to suit individual product type should be the base size and the gage block. The base size should be designed to suit the maximum size of the product or maximum size that can be manufacture whichever smaller. The gage block was the critical point checking shape; hence, each company should design a block that fits their product. In the case of PACO, the base was designed not to exceed 100cm by 50cm due to the machining limitation. The gage block was designed to fit the mounting point of each condenser and the inlet and outlet.

4. Collect the parameters of the prototype fixtures

   The same parameter data should be collected from the prototype. It was highly recommended that this data should be collected over a long period of time to observe the learning curve and remove those data points.

5. Collect the parameters of prototype operation

   The same parameter data should be collected from the prototype. It was highly recommended that this data should be collected over a long period of time to observe the learning curve and remove those data points.

6. Analyze the results

   Each parameter of the fixtures was compared between each design. The trade-off has to be identified and addressed. In short-run flexibility will have trade-offs, but in the long run, those trade-offs could be reversed. Hence trade-offs should be identified and analyzed for the short run and long run.

7. Select and implement the best design

From the analyzed data, the design with the highest net present value or cost-saving should be selected. However, a design could be select due to some unmeasurable problems such as lack of skills labors.

4.1. Results

In the production process of the prototype, there were design changes to optimize for the working environment and actual production. However, the result collected here may not reflect the most optimized design produced by the company. The result is listed according to the weight of the factor to decision making. Assumptions have to be made in order to predict some of the long-term results due to limited data collection time. The calculation of the long-term result was based on the average result collected.

4.1.1.Cost of fixture production.

Comparing the cost of the fixed fixture and the modular fixture was not a direct comparison hence the cost comparison was split into 3 types of comparison namely the cost per fixture per SKU, cost per fixture based on checking points, accumulated cost. Since the modular fixture has not been in operation long enough, some reasonable assumptions were made.

The cost of production was also related to design, machining, and material cost. The modular fixtures consist of 2 parts; the first was the standard part that requires only one-time design and production (100mm and 10mm base layers), and the latter was specific parts that require design and production for each new SKU.

A standard part will have 4 mounting points, 4 edges, 1 inlet, and 1 outlet, or a total of 10 checking points, whose cost could be calculated as follows.

Table 6 Variable table for cost calculation.

Variable	Description
C_T	Total Cost
W	Weight of the material
C_{kg}	Cost per kilogram
T	Time of machine operation
C_{op}	Cost of machine operator
C_{mop}	Cost of machine operation
C_{dep}	Cost of machine depreciation

$$C_T = W \times C_{kg} + T \times (C_{op} + C_{mop} + C_{dep}) \quad (1)$$

Currently, each fixture requires an average of 5 working days to be designed and produced. Moreover, the average production cost of a fixture was 3,000 Baht with no salvage value at the end of its lifetime.

The cost of operation and time of operation were expected to remain the same as the new fixture system will not affect the current working procedure – and so no new training, manpower, or supporting equipment was required. Moreover, as a new fixture design heavily duplicates the top gage block from the old gage, there was no difference in the inspection level.

Table 7 summarizes estimated costs for modular components.

Table 7 Estimated costs for modular components.

	Base 100mm layer	**10mm layer (per block)**	**Gage layer (per block)**
Weight of material	200 KG	2.5 KG	~1 KG
Cost of material	30 Baht per KG	30 Baht per KG	30 Baht per KG
Time of machining	60 hours	6 hours	1 hour
Cost of operator	100 Baht per hour	100 Baht per hour	100 Baht per hour
Cost of machine operation	5 Baht per hour	5 Baht per hour	5 Baht per hour
Depreciation of machine	50 Baht per hour	50 Baht per hour	50 Baht per hour
Cost Per unit	15,300 Baht	1,005 Baht	185 Baht
Number of units	1	9	9
Total Cost	15,300 Baht	9,045 Baht	1,665 Baht

From the aforesaid estimation, estimated cost and space savings can be then calculated, where Figure 26, shows both short-term and long-term costs, along with production time for all 3 modular fixture designs. The cost-saving gained from the new fixture design will be cover the initial investment cost after 14 units, 28 units and 15 units were produced for 4 level design, 3 level design, and 2 level design respectively. On the other hand, space-saving was in effect since the first unit was made.

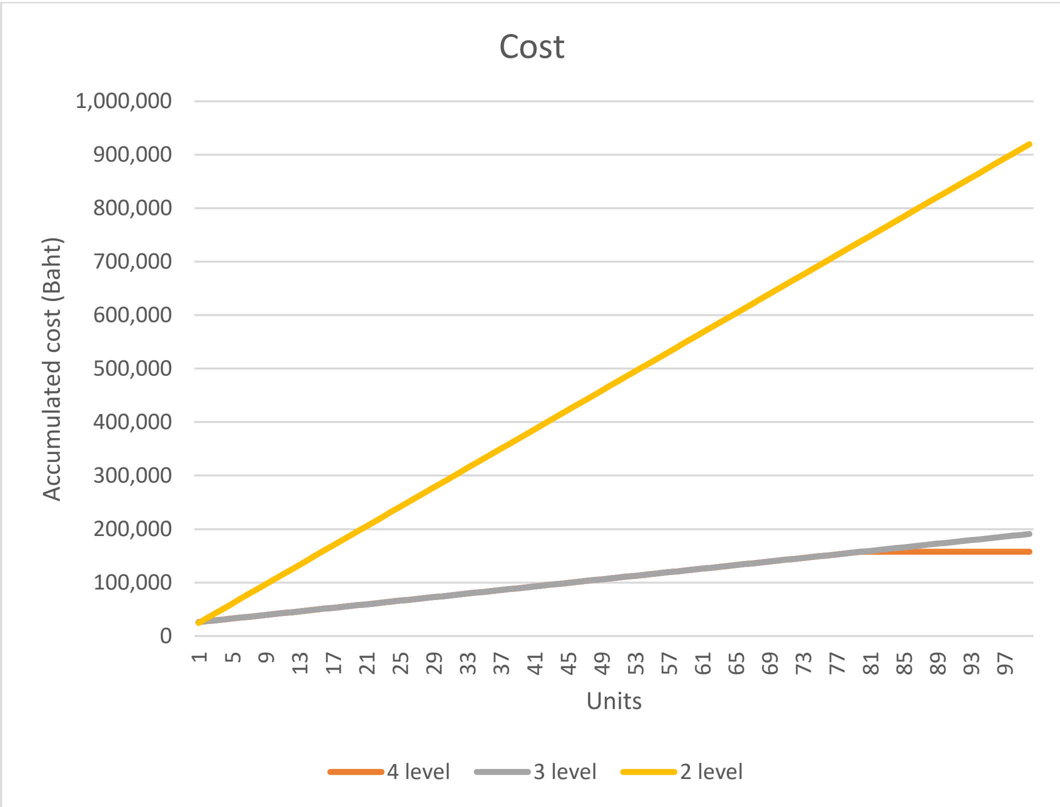


Figure 26 Cost of fixture production

Figure 26 shown the accumulated cost of production of each fixture designs up to 100 SKUs. From the data collected from Chapter 3, it could be assumed that 20% of the new SKUs share a mounting point design with the previous designs. Hence, for the 4 level design, there will be no additional cost of producing a new set of gages for a new SKU beyond the 80% point. At the point that the company produced 100 new SKU the average cost of each set of gages will be 9,198, 1,908.45 and 1,575.45 Baht for 2 level, 3 level, and 4 level design respectively.

4.1.2.Space for fixture storages.

The modular fixture consists of 2 to 4 layers depending on the design. Each design requires a different amount of storage space. The calculation of each design storage space is shown below with the graph comparing the space required for additional SKU (figure 27). The space needed to store one set of gage level for 3 and 4 level design was 0.25m by 0.3m by 0.06m, or equivalently 0.0045 m^3 each. The space needed to store one set of gage level for 2 level design was larger due to the larger base; as a result, the space required for storage was 0.25m by 0.5m by 0.2m, or equivalently 0.025 m^3 each. As the number of units increases, it was apparent that 4 level design required the least space followed by the 3 level and 2 level design respectively.

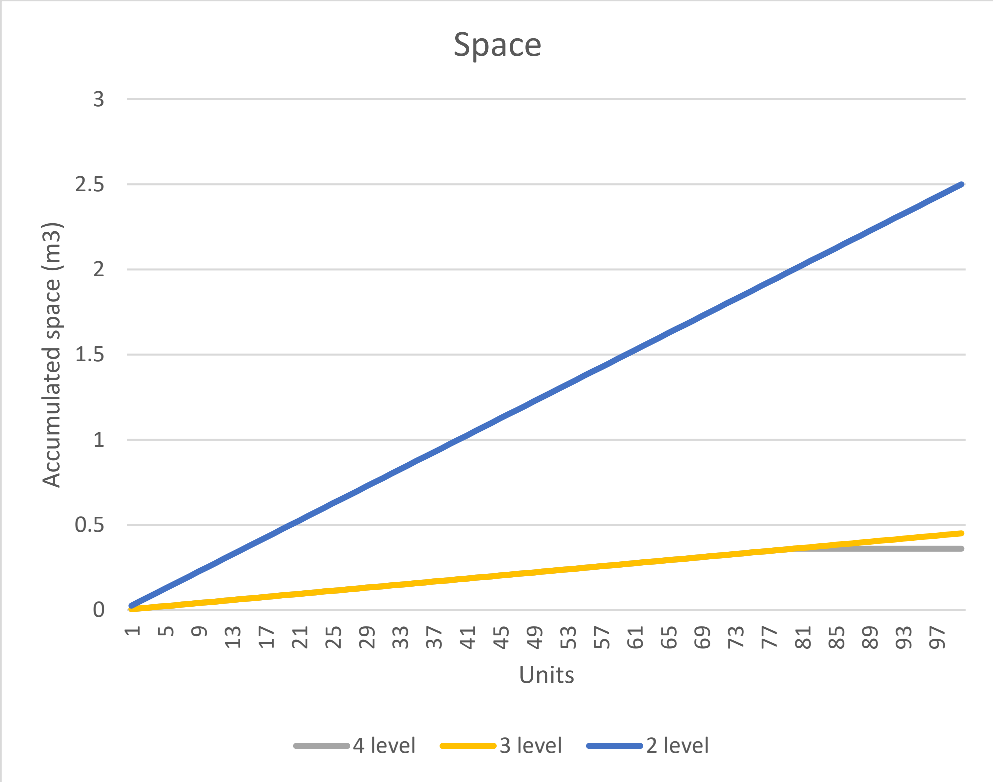


Figure 27 Storage space for each fixture design

Similarly, the storage space has a similar graph to the cost of production. Figure 27 shows the total storage space required to store 100 SKUs. From the data collected from Chapter 3, it could be assumed that 20% of the new SKUs share a mounting point design with the previous designs. Hence, for the 4 level design, there will be no additional new set of gages. Therefore, for a new SKU beyond the 80% point, the company will require no additional storage space. At the point that the company produced 100 new SKU total storage space required will be 2.5, 0.45, and 0.36 cubic meters for 2 level, 3 level, and 4 level design respectively.

4.1.3.Time of fixture production.

The fixed fixture production time was a very straight forward calculation that was time taken to produce a fixture. However, the modular fixture has multiple parts to the fixture production that were the based table, different layers, and the gage layer. Since the based table and the different layers were made only once during the system change, it was not included in the production time. The gage layer was also tricky to predict the production time since by design the gage of the 4 level design could be reused on similar designed SKU so technically that fixture will have no production time. For the closest comparison possible, the special case stated above was not accounted for, and the comparison was based on only those SKU that requires the production of a new fixture or gage level only. Table 6 shows the machine production times for each level. It roughly takes 9 machine hours and 9 working hours per each set of gage block. The working hours remain the similar as compared to the original design; however, the additional machining hours will be a significant factor in the production time. In addition, the 4-level fixture requires significantly longer to design as compared to 3 and 2-level fixtures.

4.1.4.Time of fixture setup.

The fixture setup process consists of removing the previous setup, installing a new setup, and final quality check. The current fixture design has the workflow shown in figure 28. However, the new modular fixture design has additional steps added to the workflow, as shown in figure 29 to figure 31. Since the workflow was changed, the comparison will be based on the overall time used.

Figure 28 Original fixture setup work flow

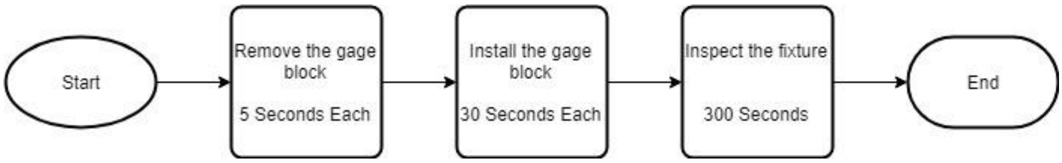


Figure 29 2-level modular fixture setup work flow

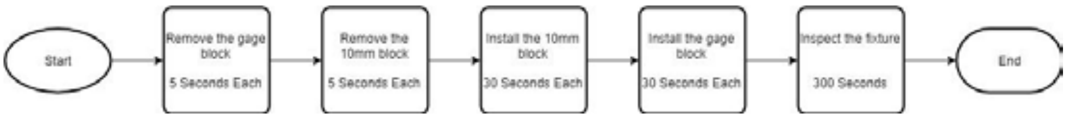


Figure 30 3-level modular fixture setup work flow

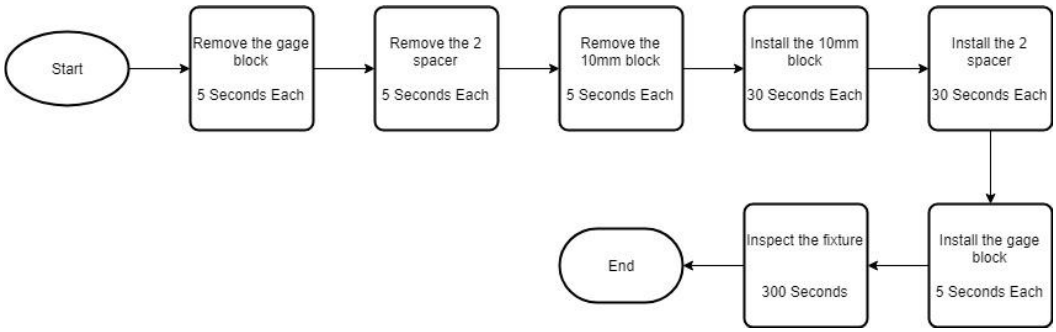


Figure 31 4-level modular fixture setup work flow

The fixture setup process consists of removing the previous setup, installing a new setup, and final quality check. The current fixture design has the workflow shown in figure 28. However, the new modular fixture design has additional steps added to the workflow, as shown in figure 29 to figure 31. Since the workflow was changed, the comparison will be based on the overall time used.

Table 8 Setup time in minutes for each fixture varies by inspection points.

	Inspection points								
Fixture Design	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Original	7.33	7.33	7.33	7.33	7.33	7.33	7.33	7.33	7.33
2 level	8.50	9.08	9.67	10.25	10.83	11.42	12.00	12.58	13.17
3 level	12.00	13.17	14.33	15.50	16.67	17.83	19.00	20.17	21.33
4 level	13.00	14.33	15.67	17.00	18.33	19.67	21.00	22.33	23.67

Table 9 Setup cost for each fixture varies by inspection points.

	Inspection points								
Fixture Design	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Original	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12.22	12.22
2 level	14.17	15.14	16.11	17.08	18.06	19.03	20.00	20.97	21.94
3 level	20.00	21.94	23.89	25.83	27.78	29.72	31.67	33.61	35.56
4 level	21.67	23.89	26.11	28.33	30.56	32.78	35.00	37.22	39.44

Table 8 and Table 9 summarized the setup time and cost of all the collected data inspection points. From the data collected in Chapter 3, it was appropriate to use the 9 inspection points for analysis. By using the 9 inspection points as a base, it was observed that the setting up the new modular fixture design would increase both time and cost by 147.72%, 227.27% and 250% for 2 level, 3 level, and 4 level design respectively. However, by observing the raw cost increase, it resulted in 4.86, 13.61, and 16.11 Baht for 2 level, 3 level, and 4 level design respectively. Since this was the cost per model change, the cost will be shared among the total number of units produced in that lot, which will be discussed in the cost of fixture operation.

4.1.5.Time of fixture operation.

This was measured straight from the number of inspected parts over a period of time. Data was collected from the operation of 29 different SKUs with 30 data points for each SKU. Average and standard deviation was calculated for each SKU and compared between the original design and 3-layer fixture.

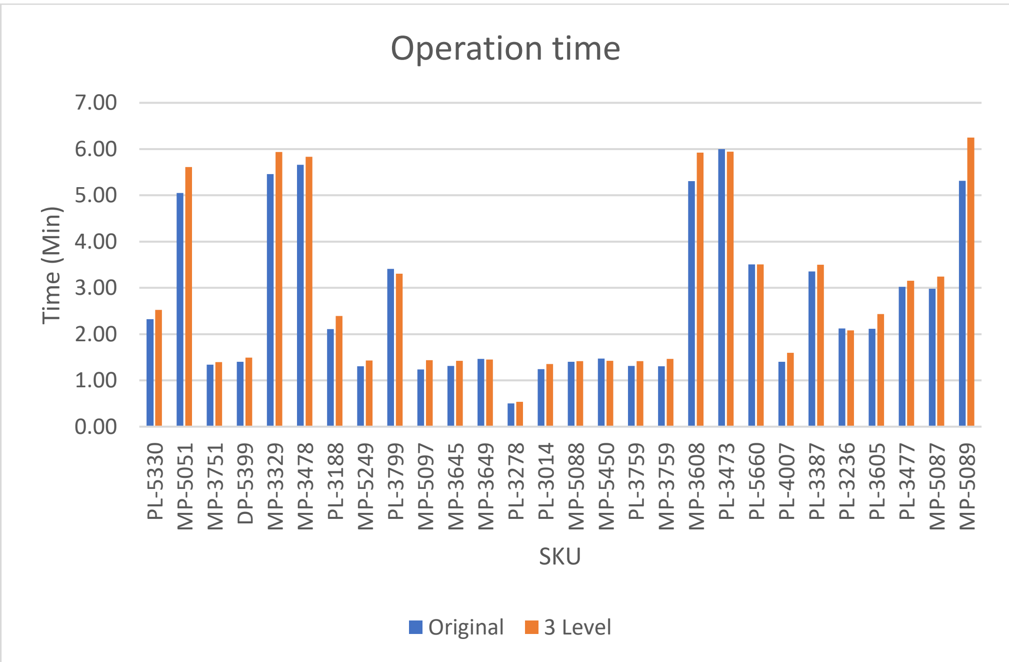


Figure 32 Operation time comparison

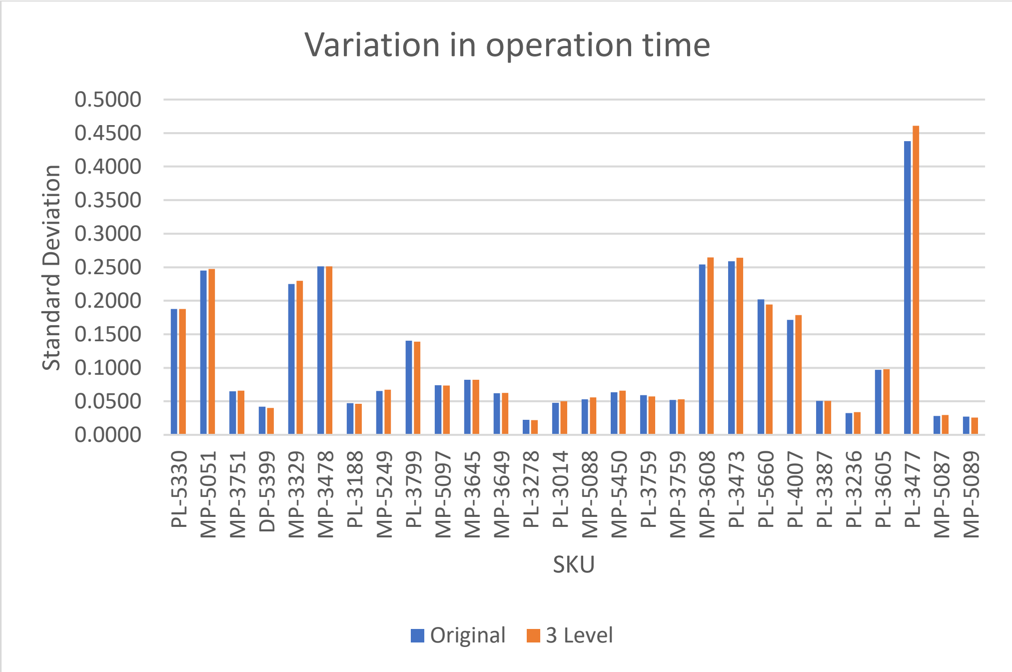


Figure 33 Variation of operation time

From data collection, it was found that most of the SKU see an increase of 5-15% in operation time. Only in 3 SKU that it was found to have an increase larger than 15%. From further investigation, those increase mainly caused by the small changes in the working movement due to the new design. The production manager forecast that the time will be reduced as the operator becomes more familiar with the new fixture.

A paired sample mean t-test was used to help determine the possible changes in the operation time. The data found to have a significant increase with a mean difference of 0.18 minutes with the upper limit of the confidence interval of 0.27 minutes.

4.1.6.Cost of fixture operation.

The cost of fixture operation was based on the working hours needed to check the same number of products. This cost also includes the setup personnel cost.

The setup time seems to have a very high increase, but this did not reflect on the increase in operation cost. Each production change will result in an increase of up to 16.11 Baht with the assumption that the number of inspection points was 9 points. With the assumption of 50 pieces per lot, the increase in cost would result in around 0.32 Baht per piece.

From the data collected in the operation time, there could be an increase of up to 0.27 minutes. However, in terms of actual manpower cost, the actual numerical cost was not revealed by the company. It could only be estimated that on average, this increase of 0.27 minutes will result in less than an increase of 0.23 Baht per piece. This has a very small impact on the total cost of production.

With both, the increase in the setup cost and operation cost the possible increase in total cost was only around 0.60 Baht per piece. According to the company, this was insignificant compared to the total production cost of a piece of a condenser.

4.1.7.Other considerations

The company had a big concern in the setup process. The company raises the question of the possible wrong set up on the 4-level design. It is possible to make a wrong setup with a mistake by using the wrong spacer. Since the increments were just 1mm, it was possible that the mistake not detected. A wrong setup could lead to wrong results or even wrong reworks. With the assumption that each condenser cost 1,000 Baht to produce an entire lot of defect will cost the company up to 50,000 Baht.

This research was based on a single workstation. The company had raised concern that sharing any gage set might not be possible if the product plan requires 2 SKUs of the same design to be produced concurrently. This would be a problem if the 4-level design were to be fully utilized.

5. Conclusion

The change in all the 6 benchmarks was summarized in the table 10 and table 11 below. The higher the number of fixtures produced will result in the higher the cost and space-saving. The effect of the increased operating cost reminds small per unit of production.

Table 10 Comparison of the benchmarks of each fixture design at first unit.

	Original	2-level	3-level	4-level	Unit
Cost of fixture production (Total)	3,000	24,345	26,010	26,010	Baht
Cost of fixture production (Average)	3,000	24,345	26,010	26,010	Baht
Space of fixture production (Total)	0.15	0.025	0.0045	0.0045	cubic meter
Time of fixture production (Per new SKUs)	8	10	10	8	Hours
Time of fixture setup (Per change)	7.33	10.25	15.50	17.00	Minute
Time of fixture operation (Per unit)	2.65	2.83	2.83	2.83	Minute
Cost of fixture operation (Per unit)	2.45	2.70	2.88	2.93	Baht

Table 11 Comparison of the benchmarks of each fixture design at 100 units.

	Original	2-level	3-level	4-level	Unit
Cost of fixture production (Total)	300,000	919,800	190,845	157,545	Baht
Cost of fixture production (Average)	3,000	9,198	1,908.45	1,575.45	Baht
Space of fixture production (Total)	15	2.5	0.45	0.36	cubic meter
Time of fixture production (Per new SKUs)	8	9	9	8	Hours
Time of fixture setup (Per change)	7.33	10.25	15.50	17.00	Minute
Time of fixture operation (Per unit)	2.65	2.83	2.83	2.83	Minute
Cost of fixture operation (Per unit)	2.45	2.70	2.88	2.93	Baht

The analysis will follow the weight of each factor. Some factors might not favor the switch to the new flexible, but the overall result has to be considered. The result shows that the modular fixture performs better as compared to the original fixture for the top 3 factors. Among the 3 designs, the 4-level design produces the most improvements. However, the setup time was significantly higher than other designs even though the setup time was not a significant factor toward decision making, but since the time difference was relatively big, this will impact the decision. The time and cost of fixture operation remain relatively the same. This means that the new modular fixture design will not require any change in operation. The cost of operation was mainly affected by the setup time.

This paper explores preliminary trade-offs from switching the designs of fixtures from traditional to modular one, where the switch will reduce the space and cost of the fixture but will increase production and operation time. However, the possible mistake in setup and the possible concurrent usage of gage sets, as stated in Chapter 4 make the company prefer the 3-level design. At the same time, with the unpredictable trend of the design, it was possible that the forecasted commonly used gage set might not hold. This would hinder that possible cost saving of the 4-level design. Nevertheless, the decision on the effectiveness of this new design was very subjective as it depends on the management perspective, i.e., the value of space-saving. Based on the estimated figures, it was believed that the modular fixture will be beneficial for both short-term and long-term objectives of the case study company as it gives the company an increase in competitive advantage that they currently have.

5.1. Limitation

The fixture design was based on PACO's condenser production process, and other companies might have different production processes that would gain the same level of benefit of this research. The new company will have to collect the new set of data and compare it before deciding on the most suitable design for that production process.

This thesis based on the latest 105 out of the 1800 SKUs that the company was producing; hence, the data will not reflex the entire data set. However, this would give a reasonable estimate of the most recent trend of the condenser design.

Due to the ever-changing market trend and design trend, the data from the past might not reflect the number in the future. One of the possible changes was in the number of common designs of each automotive brand. Another possible change in the future is the design becoming obsolete; this will affect the future new design required for the new SKUs.

5.2. Future Improvement

The company decided to move forward with the 3-level design due to many other factors such as ease of design, ease of production, and ease of setup. Some of the areas of possible improvement are in the work process of design, production, and setup.

Currently, the design process uses the same design process as the previous design. This process starts with measuring the distance between each mounting point and designs the gage from that point. However, since the new design requires the first gage block to start as the point of origin, the design procedure has to change. Since each movement was 10mm, each SKU will require a new design. When changing the design mentality, the 4-level will be easier to design since the movement of each step was 1mm, it was possible to reuse common gage. In order to use CAD, a calculation was required, but if prototype or sample parts were available for reverse engineering, it was possible to use the try-and-error method to get the right setting.

The setup processes for 3 and 4 level design were shown in Figures 30 and 31. The assembly of gage level, spacer, and 10mm level does not require to be set up at the operation table. Hence if the setup technician would set up this step before making the model change for 3 and 4 level design, this could save 35 seconds and 45 seconds respectively for each mounting point. This would not save the setup cost since the time required for the technician remains the same; however, this will save time for a model switch.

Lastly, the current modular fixture design focuses on the inspection of condensers. The condenser designs were mainly 2 dimensional; hence, the fixture design mostly suits 2-dimension inspections. This modular fixture could be improved to inspect 3-dimension parts in the future. This could be done by adding the angle base plate to the system. Alternatively, various support elements and specialized gage block could increase the flexibility in the height dimension. However, these changes could give a different result in the trade-offs, so further data collection and analysis have to be carried out.

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