

Assessment One

Design, Development and Manufacturing – 3 Jaw Cobot End Effector

Module:	Manufacturing, Technology & Design – ACMA 5002
Author	John McDyer - 2010064

Table of Contents

Introduction	3
Concept Design Appraisal	4
Quality Function Deployment (QFD)	7
Product Design Specification	8
Manufacturing Process Proposal.....	12
Design and Development	13
Design for 'X'	13
Efficiency.....	13
Assembly – Lucas DFA Manual Handling Analysis	15
Assembly – Lucas DFA Manual Fitting Analysis.....	15
FMEA	16
Final Design Discussion.....	17
Outsourced parts	18
Environment / Product lifecycle.....	19
Manufacturing Process Design.....	20
Process Flowchart Description.....	21
Conclusion	22
Appendix	23
Works Cited.....	24
Bibliography	25

Introduction

In modern day production, robots are becoming more common place within manufacturing facilities and interacting with humans ever more; these are known as cobots. A prototype design was submitted of a manipulator arm that could be fitted to a cobot and there was a requirement to continue with an appraisal of the design. The manipulator arm was required to handle a number of different size objects and work in a variety of environments depending on the use of the cobot. It was the anticipation that the final design required a production output of 1000 to 2000 units per week.

The aim of the project was to scrutinise the design and advise on any improvements that could be made at technical drawing stage and to carry on the design process through to production and final assembly. This included exploring suitable mass manufacturing techniques that could be used. During this process, the design has also been assessed using methods such as quality, function and deployment, design for 'X' and failure mode effect analysis. A major challenge of the project was the initial design missing key features such as dimensional tolerancing elements and missing key components such as connection pins, stopper plates, etc.

The final conclusion that has been produced in this report has sustainability and cost implications at the centre of its discussions. These two main points have been consistently considered to achieve a balance of the most viable, environmentally friendly and cost effective process for the design outcome.

Concept Design Appraisal

During the appraisal, it is important to keep the customer's design requirements at the forefront. The customers design requirements are as follows:

1. Adaptable – To be used with a number of differing parts
2. Hard wearing
3. Use in a wide range of environments
4. Resistant to chemicals, dust etc
5. Easy to maintain
6. Relatively cheap to produce (manufacturing processes must be justifiable)
7. Materials and parts should be recyclable and ethically sourced

To appraise the design in more detail, it would be pertinent to look at the design as a whole, however, at certain points focusing on individual components will be required for a more in depth scrutiny. Using this approach, each part of the design will have its own specific needs and discussions, and will give more clarity on the appraisal of each part without confusion.

The design as a whole has a number of points that need to be addressed. There is a clear lack of fixings for the mounting of the arms and the motor and there is no consideration for the assembly of the design. The holes for the mounting points have no leading edges or chamfers which will greatly increase the difficulty of assembly, which adds time and effects cost. Another area that could improve the assembly and maintenance of the design is the jaw mounting clevis points on the cylinder. There are no grease nipples to provide adequate lubrication to the mounting pins. The jaw and clevis both have a dimension of 5mm with no tolerance. This would make it very difficult for the jaw to move freely during operation and would also create friction points on the faces increasing wear rates. With regards to the pins that are required to assemble the jaws, it is suggested that a H7/G6 locational clearance fit be used for ease of assembly and accurate movement [1].

There appears to be no consideration for the sharp edges on the jaws in particular, which gives the part an unappealing look with the additional issue of safety to the user and maintenance teams.

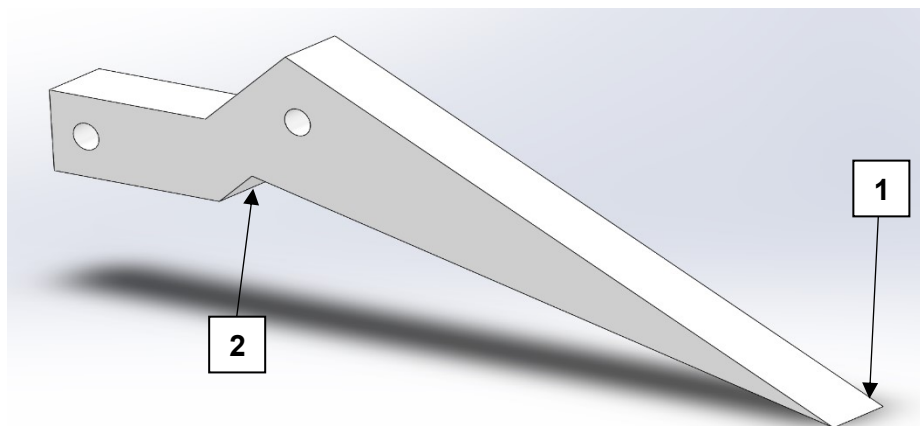


Figure 1

The jaw section of the assembly requires the largest changes to its design. First and foremost the gripping end of the arm has a very small cross sectional area and this will make the arm prone to breaking off at the tip, see point 1 in figure 1. In addition to this, the arm may develop surface defects such as nicks, cuts, cracks and gouges (NCCG)

which will all have a detrimental effect on the gripping operation of the arm. The second point that stands out is the aesthetic feeling of the arm. There are a number of sharp edges which do not give a pleasing look to the eye but also do not provide any functional benefits, in fact they give the opposite effect. With no radius being used at any intersections, this gives concerns for 'stress raisers' as indicated by point 2 in figure 1. To support this notion, 'It is well-known that, for some real notched engineering components, cracks do not initiate at the stress raiser tips, but in the interior area of the component, i.e., away from the highly stressed regions' [2]. This is also shown in figure two where it can be seen a far lower local area stress can be achieved by using a larger radius at plane intersections.

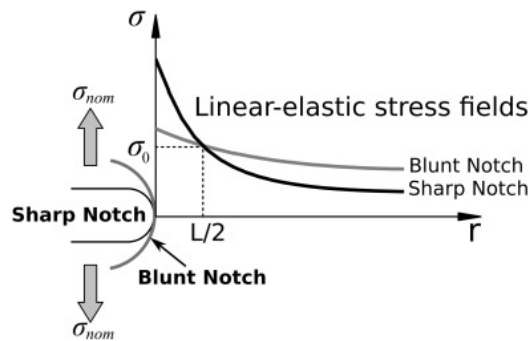


Figure 2 - [2]

Thirdly, taking the assembly as a whole, the design of the jaw does not allow the jaws to close completely. This will limit the diameter of objects that can be picked up by the robot. This can be eliminated by utilising a cylindrical face to the gripper arms which will allow nearly full closure of the three jaws. In figure 3 it can be seen in greater detail where the flat face of the jaw prevents the jaws from closing.

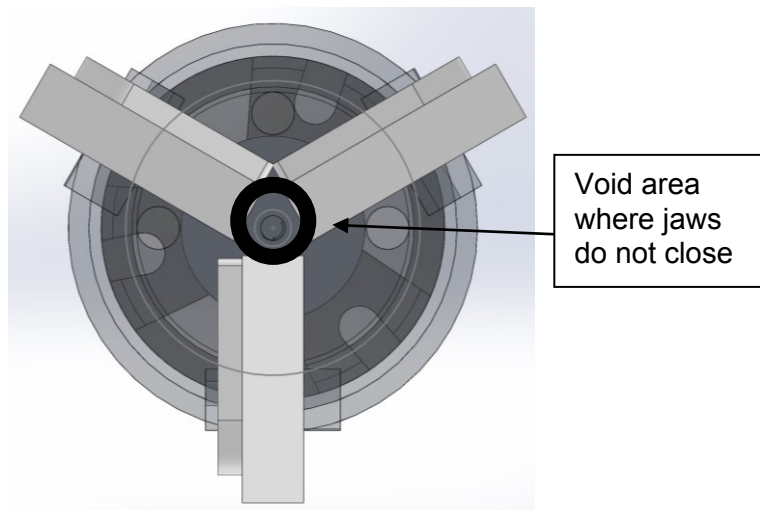


Figure 3

By improving these three main areas of the manipulator arms, there will be clear benefits to the outcome of the design. These proposed changes will improve time of use in service and lower chance of developing defects during cyclic use. Lastly, the operation will have a larger range of grip diameter which enables the gripper to pick up a wider range of product. Included in these changes will be the smaller elements such as counter sinking of location bores for easy assembly and removal of all sharp edges.

In the worm drive part of the design, it is apparent that there is no connection point for the drive motor. In its current state, there would be no way for the output shaft of the motor to drive the worm. This would be required to be modified to accept a more standard connection type such as a jaw coupling (spider) shown in figure 5. This type of coupling allows for marginal misalignment and has excellent torque absorption capability. In addition to this, the jaw coupling is readily available, cheap and lightweight [3]. If the design was changed to accommodate this type of coupling then the shaft section of the design could also be removed.

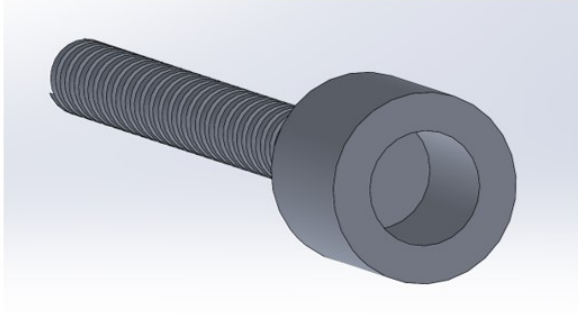


Figure 4



Figure 5 - RS-online.com

Overall, there are a number of key areas to improve the design. The areas discussed will improve the functionality, aesthetics, maintenance and assembly of the initial concept design. Each area has its own importance to the customer and will reduce costs in the longer term. If we relate back to the Quality Function Deployment (QFD) section of this appraisal, it can clearly be seen that the availability of spare parts, standardisation and being able to pick up a wide variety of parts take priority with the needs of the customer. The changes that have been proposed will address these priorities adequately and will certainly improve the design overall.

Quality Function Deployment (QFD)

Legend	
Strong Relationship	9
Moderate Relationship	3
Weak Relationship	1
Strong Positive Correlation	
Positive Correlation	
Negative Correlation	
Strong Negative Correlation	
Objective Is To Minimize	
Objective Is To Maximize	
Objective Is To Hit Target	

Title: 3-Jaw Cobot End-Effector														
Author: John McDyer - 2010064														
Date: 4th June 2021														
Notes:														
1. QFD exercise for the analysis of a cobot manipulator.														
2. This exercise has been completed by only the author.														
The options in this document may be subjective due to														
the lack of collaborative input.														

Product Design Specification

Three Jaw End Effector

1. PERFORMANCE

1.1. The product shall be expected to work a continuous 24 hour shift pattern.

Approximately 60 cycles per hour.

1.2. The product must not induce any extra health and safety hazards.

1.3. Must be robust/hardwearing to withstand the daily use.

1.4. The product should not slow down the existing process.

1.5. The product shall not require any change of current processes.

1.6. Must be flexible enough to pick up a variety of parts.

1.7. Must have variable grip force settings.

1.8. Design must allow human interaction.

2. WORKING ENVIRONMENT

2.1. Small to medium industry.

2.2. Dusty and dirty environments.

2.3. Should be able to withstand very high and low temperatures ad jaw section.

2.4. General ambient use temperature range is -40°C to 100°C.

2.5. Shall withstand numerous knocks and light damage.

2.6. Abrasive conditions.

2.7. Use near chemicals / solvents.

3. LIFE IN SERVICE (PERFORMANCE)

3.1. The product shall expect to have a number of years of life in a variety of harsh environments.

3.2. Manipulator arms must last at least 3 months in service.

3.3. The product will be in use on a continuous shift pattern, 5 days a week. 24hrs x
5 days = 120hrs per week.

4. MAINTENANCE

- 4.1. Parts should be readily available on the engineering market.
- 4.2. No specialist tools shall be required to maintain the design.
- 4.3. Shall be low cost to maintain.
- 4.4. No special training should be needed to maintain the design.
- 4.5. Parts should be quick in nature to change (gripper jaws in less than ten minutes)

5. PRODUCT COST

- 5.1. Manufacturing costs should be kept to a minimum and be justifiable.
- 5.2. Spare parts should be low cost to purchase.

6. QUANTITY

- 6.1. 1000 to 2000 units per week must be produced.

7. MANUFACTURING FACILITY

- 7.1. Product shall be made within standard manufacturing facilities.
- 7.2. Standard CNC / Manual lathes, water/laser cutting, milling machines and drills required.
- 7.3. Quality control techniques to be used during production.

8. SIZE

- 8.1. Product shall not be of a disproportionate size compared to the cobot arm.
- 8.2. The products size should not impair the cobots ability to lift materials in tight/awkward locations.
- 8.3. Design should be a suitable size for shipping worldwide.

9. WEIGHT

- 9.1. The maximum weight should be 2kg (allowing the cobot to lift 8kg).
- 9.2. The weight must not adversely affect the operation or weight distribution of the cobot.

10. AESTHETICS, APPEARANCE AND FINISH

- 10.1. The product should have a smooth finish.
- 10.2. All sharp edges should be removed.
- 10.3. The design shall have a professional finish e.g. no rough machining.

11. MATERIALS

- 11.1. The product shall be made from lower cost, readily available material such as mild steel.
- 11.2. The material shall be able to withstand a number of environments, if not treatments should be applied.

12. STANDARDS AND SPECIFICATIONS

- 12.1. The product design must comply and not cause conflict or interference with BS EN ISO 10218 Safety requirements for Industrial robots.
- 12.2. The product must pass all tests as detailed in BS ISO 18646-3:2021 Performance criteria and related test methods for service robots. Part 3: Manipulation
- 12.3. Must comply with supply of machinery (safety) regulations 2008 including any documents supplied.
- 12.4. Product must meet BS EN 60529 for I.P. rating of equipment

13. CUSTOMER

- 13.1. The customer has stated that the product must have an equivalent or lower risk assessment rating than the current operation.
- 13.2. The design must not introduce new hazards to the workplace.
- 13.3. The design should not slow down the operation process.
- 13.4. All materials shall be ethically and sustainably sourced.

14. QUALITY AND RELIABILITY

- 14.1. The product shall be reliable and have minimal downtime i.e. 98% availability.
- 14.2. Any welded connections should be NDT tested to ensure continuity.

- 14.3. All machining quality standards shall be adhered to.

15. TESTING

- 15.1. NDT testing shall be carried out on welded connections.
- 15.2. Factory tests for the product to be carried out to ensure safety and functionality. (Please see section 12)

16. SAFETY

- 16.1. Must follow any guidelines / regulations as stated in HASAWA 1973.
- 16.2. The design must not create any additional hazards to the user.

17. COMPANY CONSTRAINTS

- 17.1. All designs should be exclusive to purchaser and not be made available publicly.
- 17.2. All information gathered is protected under UK Privacy policy.
- 17.3. Non-disclosure agreement shall be signed for initial drawings obtained from employing company.

18. PATENTS, LITERATURE AND PRODUCT DATA

- 18.1. Other products on the market shall be searched for patent design prior to final design drawings being made available.

Manufacturing Process Proposal

During the selection of the manufacturing processes, there needed to be a clear justification for cost and ability of each machine. The client required a machine that met their needs for production but at a price point that was acceptable for the business. For instance, water cutting versus laser cutting. They have similar principals but at different price points and ongoing costs such as energy and material use. If we look at the ongoing energy costs, then this has a bad effect on the environment as well as the additional business running rates. This is just one example of the justification process.

The initial plan for the manipulation jaws and joints is to create the parts from sheet metal and use the production method of laser cutting. Sheet metal is readily available in the market with various properties which enables the jaws to be made from a material required by the customer with no change in tooling or machines. CNC Laser cutting has been chosen over other manufacturing processes as it suitable for cutting high accuracy of up to approximately 20mm thickness depending on the material [4] and has the ability to cut a range of materials. Unlike other machines, there is no tooling changeover required as the intensity of the laser is adjusted for the material choice which gives extra flexibility to material choices and design changes [4]. The modern 5 axis laser cutting machines are capable of cutting radii into sheet metals with ease and can also have conveyor fed systems reducing the need for manning, however, this extra feature would have to be feasibility checked via a cost study. For the production process, sheet metal would be loaded into the machines 'hopper' which will then transition into the machine via a conveyor. The CNC programme will run ensuring that it is setup for the most efficient cutting coordinates and to produce minimal waste. To further improve the efficiency of the machine, the sheet metal can be 'stacked' so in essence doubling production output with only a small time delay in the cutting process [6]. The parts would then be required to be finished on a CNC milling machine for the reaming of cut holes and chamfers.

For the production of the cylinder, it is proposed that permanent mould aluminium castings are bought in via a supplier. This type of casting was chosen over injection casting and sand casting due to the volume of parts required and the level of investment available. Sand casting takes on average five times longer than permanent mould casting [7], and the tooling costs that would be required for injection moulding are very high [8]. Given the basic nature of the shape and the minimal features that are actually required to be machined (for instance only pin bores, clevis plates and motor mounts are required to be machined), the majority of the part could remain with a cast surface finish. The parts will then be finished using in house production CNC milling machines. The CNC milling machines provide more than enough capacity for the output required at the desired accuracy.

The CNC milling machine would also be used to manufacture the drive plate from mild steel bar providing the selected machines offered the flexibility of a tool belt for quick and easy tool changes. The CNC would be set up with both programs pre-loaded and two separate jigs on the machine table. This would enable the machine to switch between programs with ease and with minimal downtime.

It has been previously discussed in the design appraisal that the worm drive will be simply modified with a straight shank and flat face to accommodate a standard jaw coupling secured with a grub screw which will also remove the need for the drive shaft. However, it should be further considered that an external leadscrew could be outsourced and mounted directly to the motor. The motor itself will be outsourced to an external supplier.

Design and Development

Design for 'X'

Efficiency

Using the essential parts decision tree in Appendix 1, an essential parts list has been developed. This will aid the thought process in attempting to design out any non-essential parts and will be following the design for assembly principle.

Part Name	'A' (Essential)	'B' (Non-Essential)
Jaw	✓	
Jaw pins		✓
Jaw pin retainers		✓
Cylinder	✓	
Drive plate	✓	
Motor	✓	
Motor mounting bolts		✓
Joints	✓	
Joint pins		✓
Joint pin retainers		✓
Shaft		✓
Worm	✓	
Design Efficiency (6 / (6+6)) x 100 = 50%		

Table 1 – Prior to amendments

Without large scale fundamental changes to the prototype design such as using a draw bar method over screw thread, a majority of the main parts are categorised as essential. This directed the focus of designing out the drive shaft and any of the unrequired fasteners. Ideally a target efficiency would be applied and the design tweaked to ensure that the target is met.

Part Name	'A' (Essential)	'B' (Non-Essential)
Jaw	✓	
Jaw pins		✓
Cylinder	✓	
Drive plate	✓	
Jaw Coupling	✓	
Motor	✓	
Motor mounting bolts		✓
Motor coupling		✓
Joints	✓	
Joint pins		✓
Worm	✓	
Design Efficiency $(7 / (7+4)) \times 100 = 63\%$		

Table 2 – Post to amendments

As can be seen in the comparison of table 1 and 2, by utilising the design for 'x' approach it enabled the focus of the investigation to minimise the connection points by removing the need for a drive shaft by the way of utilising a jaw coupling and also removing the need for split pins for securing the joint pins and jaw pins. The preferred method is now to use an encapsulated spring loaded ball bearing on each of the pins which will standardise the part and greatly improve the assembly efficiency. These two changes have improved the assembly efficiency by 13%.

Assembly – Lucas DFA Manual Handling Analysis

Part Name	A -Size and weight of part	B - Handling difficulties	C -Orientation of part	D - Rotational orientation of part	Total
Jaw	1	0	0.1	0.1	1.2
Jaw pins	1	0.2	0	0	1.2
Cylinder	1	0	0	0	1
Drive plate	1	0.2	0	0.1	1.3
Jaw Coupling	1	0.2	0.1	0.1	1.4
Motor	1	0	0	0	1
Motor mounting bolts	1	0.2	0	0	1.2
Motor coupling	1	0.2	0.1	0	1.3
Joints	1	0.2	0	0	1.2
Joint pins	1	0.2	0	0	1.2
Worm	1	0	0.1	0	1.1
TOTAL					13.1

Table 3

Assembly – Lucas DFA Manual Fitting Analysis

Process	A - Placing and fastening	B - Process direction	C - Insertion	D - Access and vision	E - Alignment	F - Insertion force	Total
Fit motor to cylinder	6	0	1.2	0	0	0	7.2
Fit coupling to motor and worm drive	6	0	0	0	0.7	0	6.7
Thread drive plate onto worm	1	0	0	0	0	0	1
Attach joints to drive plate	6	0	1.2	0	0.7	0	7.9
Fit jaws to cylinder	6	0	0	0	0	0	6
Attach jaws to joints	6	0	1.2	0	0	0	7.2
TOTAL							36

Table 4

As can be seen in tables 3 and 4, the design has been analysed using the Lucas Design for Assembly method. This method helps set a bench mark on the design and gives the designer a comparison score to see how well the design can be handled and assembled against competitors designs. Each area can then be further broken down and for a more in depth analysis to see how the design can be improved and made more efficient for the assembly stage.

Final Design Discussion

As discussed in the design appraisal, the jaws required the largest changes to improve the design. There were a number of intersectional areas where no radii were applied and the lack of counter sunk bores inhibited assembly. In addition to this, there was an area where the gripper jaw had a lack of cross sectional area which made the tips of the grippers weak. Only one area that has not been shown in figure 6 is the cylindricity that was to be added to the end of the gripper to reduce pick and place diameter (please refer to figure 3). This was due to the limited access to CAD applications and the issues transferring file types. Tolerances have also been added to the mounting points which allow a H7/G6 locational clearance fit that will give enough accuracy for the arm to move while making it an easy hand assembly fit. This would give a tolerance on the 5mm holes of $+0.012\text{mm}$ and -0.0mm .



Figure 6

Other part modifications include a larger hole diameter (Figure 7) in the cylinder to accommodate the new jaw coupling and the flat face modified into the worm to also accommodate the jaw coupling.

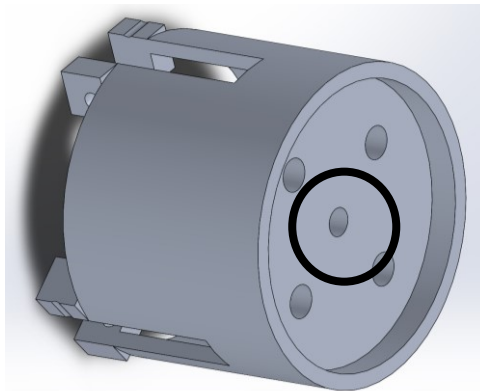


Figure 7

Outsourced parts

- Variable torque AC motor is readily available on the market and if has been decided to outsource this part.
- Fasteners to be used are standard ball retaining clevis pins which allow quick and easy maintenance.



Figure 8 – RS-online.com

Environment / Product lifecycle

It is paramount that during the design process and material sourcing of the product, that the lifecycle is considered to ensure the environmental impact is kept to a minimum. 'The goal of product life-cycle engineering is to maximize the values of the manufacturer's line of products, while containing its costs to the manufacturer, the user, and society. Engineers must consider performance, costs, and environmental impact. In the past decade, researchers around the world have proposed various systematic methodologies that apply to the early stages of product development in integrating life-cycle quality' [9].

Taking the above statement into the discussed design, each part is enabled to be stripped back and separated into its individual components enabling the product to be reused or recycled. As can be seen in figure 9, the preferable method of lifecycle is reuse or recycle which gives the product a new purpose and lease of life. This in turn decreases the requirement for new raw materials to be utilised. For instance, when a jaw arm wears, the steel/aluminium/plastic part can be recycled. If we take the pins into consideration, they can be reused a number of times before the wear rates deem the part unserviceable. All of these thoughts are taking into account the environment and lifecycle of the product.

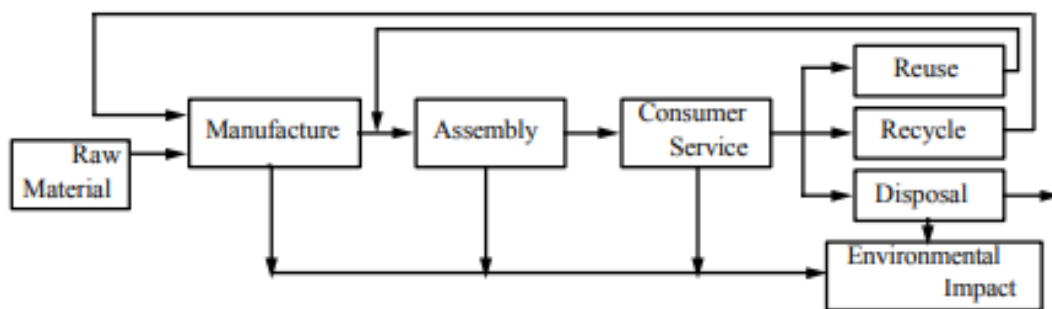
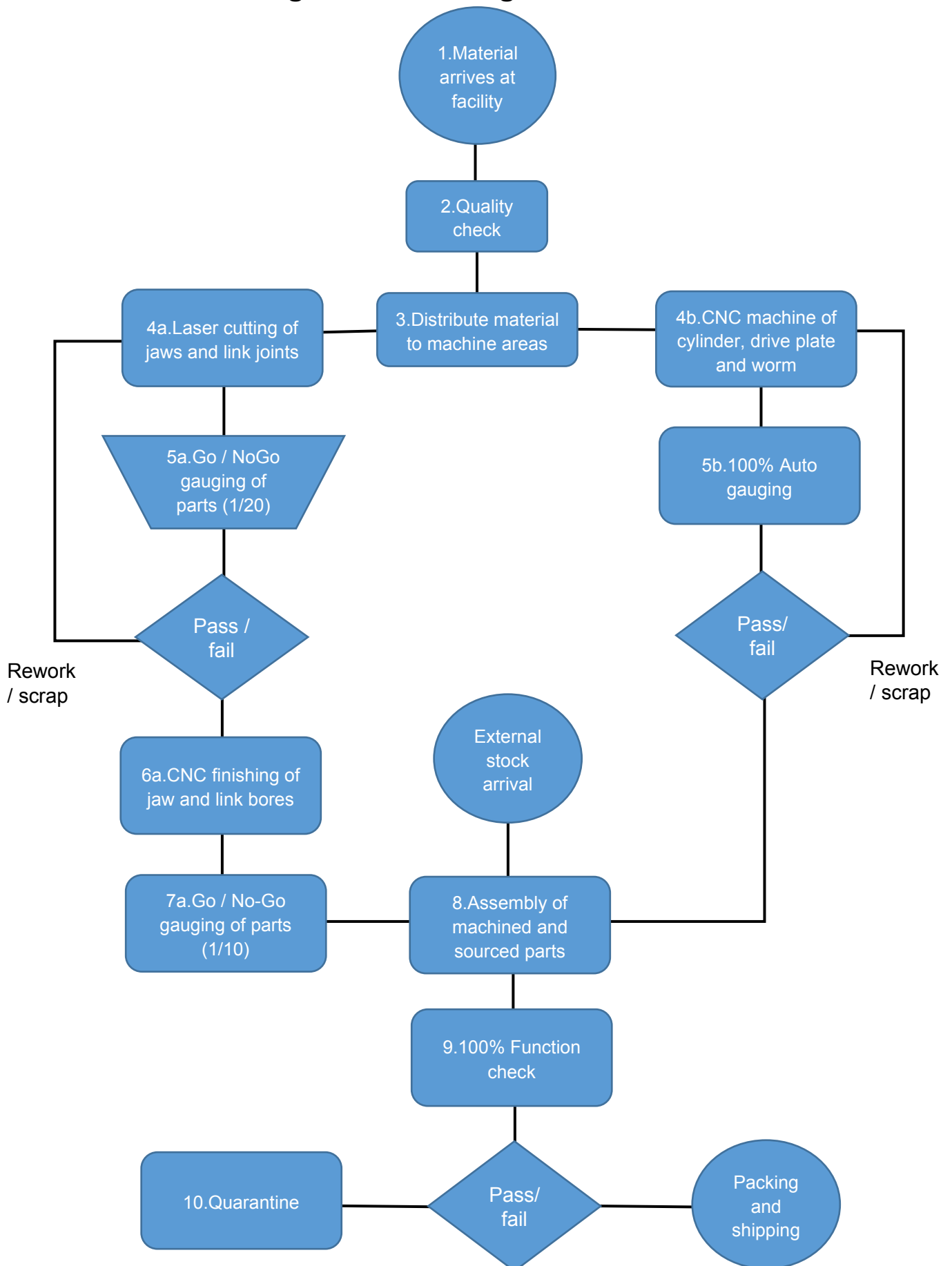


Figure 9- [9]

Another important consideration is the sustainable sourcing of products. There is an ever increasing pressure on products to be sourced ethically and companies are being held responsible for the sourcing methods [10]. Supply chains are continually growing and companies are seeking ever lower costs for their products which inevitably moves procurement to the direction of third world countries for lower costs. Within this design project if materials are sourced sustainably there are a number of benefits to the project such as mitigating business risks, increased competitiveness, speeding up innovation and improves the business image [11]. All of these aspects add to the value of the product so should be considered carefully.

Manufacturing Process Design



Process Flowchart Description

Proces No:	Description
1	Raw stock arrives at facility from supplier in a lean manufacturing process ensuring no over storage of stock preventing waste
2	Visual inspection carried out to verify stock compliance to order detail. Possible introduction of part sampling depending on supplier consistency
3	Material sorted and sent to machining lines in a just in time fashion to avoid material backlog
4a/b	Machining carried out by laser cutting and CNC machining
5a	Error proofing - Go no go gauging of jaws and links. 1 in 20 check and operator given permission to halt production. Examples of Go/NoGo:   Image from YPG-Limited.com Image from Polygonsolutions.com
5b	Error proofing - 100% line gauging for the higher tolerance fits. This is carried out by automated gauging such as Marposs or Intra gauging systems
Decision block	Parts will either be reworked or scrapped depending on failure margins
6a	Further machining of laser cut parts to ream out holes and counter sink bores
7a	Error proofing – Go no go gauging on bores 1 in 10 check
External stock	Parts arrive from supplier in a lean manufacturing style and are sent to the assembly line in a Just in time method. This ensures no backlog of parts and wasted revenue
8	Assembly of machined parts and outsourced motor and pins. The assembly process will be completed as a sequence operation with each operator having their own responsibility
9	Error proofing – 100% function check of motors and operation of gripper arm.
10	Parts are quarantined if they fail the function check and further investigation required.
End	Parts sent to packing area for shipping to customer.

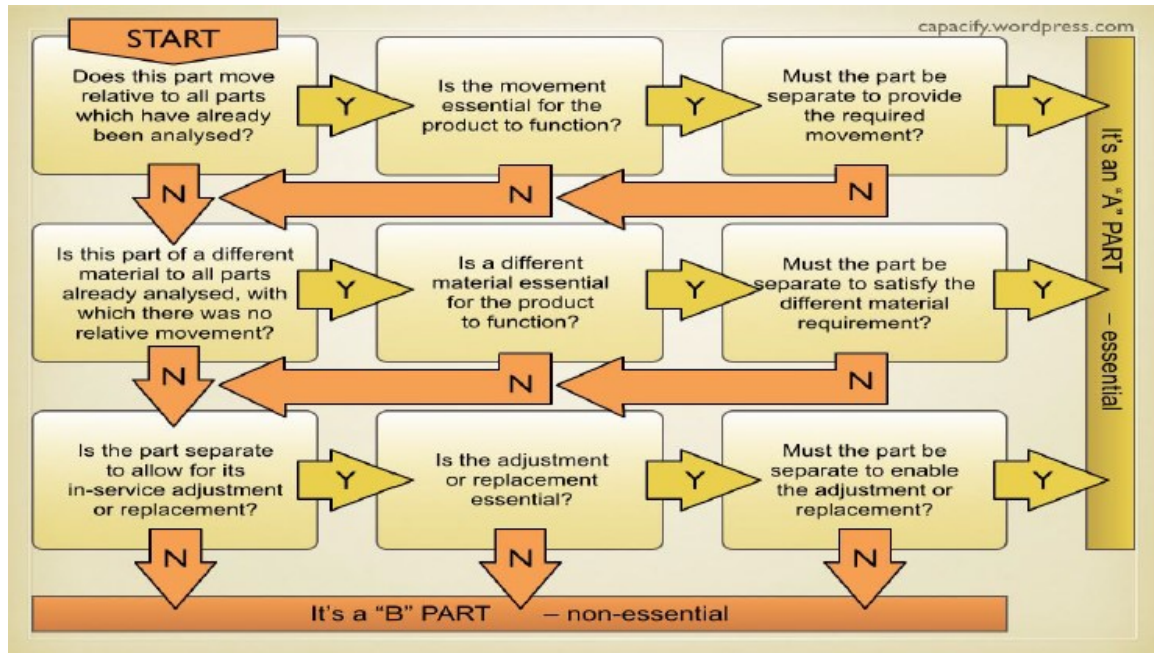
Conclusion

From the first design prototype there have been many discussed changes and product improvement techniques used. It is clear that the standardisation of parts has given the design an efficiency increase of 13% and I am confident that with further in depth development the Lucas method index for assembly could be decreased by a large margin. The manufacturing methods that have been researched and advised offer the best use of the chosen machinery by ensuring their flexibility to accommodate a number of different parts with minimal tooling changes. This is evident with the laser cutting machine where different materials and parts can be cut just with a change of program. The manufacturing process section of the project encapsulates lean manufacturing techniques and just in time to ensure that overhead and waste are kept to a minimum. To further bolster this technique, 'Poke Yoke' has been introduced to error proof the process and ensure the customer receives the part as per their specifications.

Overall, the design has been analysed, modified and implemented to increase the quality, efficiency and safety for the customer. It is evident that the part and production processes meets the design brief set out at the start of the project and would be a feasible design to carry forward into production.

Appendix

1)



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