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Design for X Project

Manufacturing Design & Technology AMCA5002

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1 Abstract

This report focuses on the range of methods and techniques that can be applied to design problems in order to assess and optimise those designs with known goals in mind. A multitude of analytical techniques were deployed to help assess design problems at both the part and assembly levels. These design assessments focused on the voice of the customer, and the use of engineering principles to translate these into technical requirements needed for effective development.

These technical requirements were filtered based on which would have the greatest impact regarding the stated goal of a given redesign objective; the remaining requirements were also key in helping mitigate the possibility of design aspects external to the consideration of this report from being impacted by any design changes.

These technical requirements were developed using analytical and technological methods relevant to the goal of the stated design and development. These changes were crucially tracked through performance metrics in order to improve and optimize the given design against the specified goals and voice of the customer. The overarching goal of these changes was to fully understand how these types of methodologies can be applied and combined to optimize the means of designing manufactured parts to suit their end requirements.

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2 Robot Gripper Redesign

2.1 Introduction

As the demand for automation continues to surge, the need for reliable, cost-effective robotic solutions capable of mass production has become increasingly important. In response to this imperative, robotic tooling manufacturers are seeking to optimize their designs for scalability and affordability. This report aims to present a review of the redesign process for a mechanical gripper solution initially produced in small volumes.

Key considerations include design optimization, material selection, manufacturability, assembly efficiency etc. To achieve this, this report looks at and applies methodologies such as design for X through the redesign process. These techniques are used to offer actionable recommendations and to focus design decisions by optimizing products for specific performance requirements, in this case, manufacturability, which helps eliminate costly alterations in post-production (Sharp, 2022).

2.2 Concept Design Appraisal

Figure 1 below is a QFD performed using the initial design currently being manufactured. This QFD will be crucial in efficiently developing this design for larger-scale production.

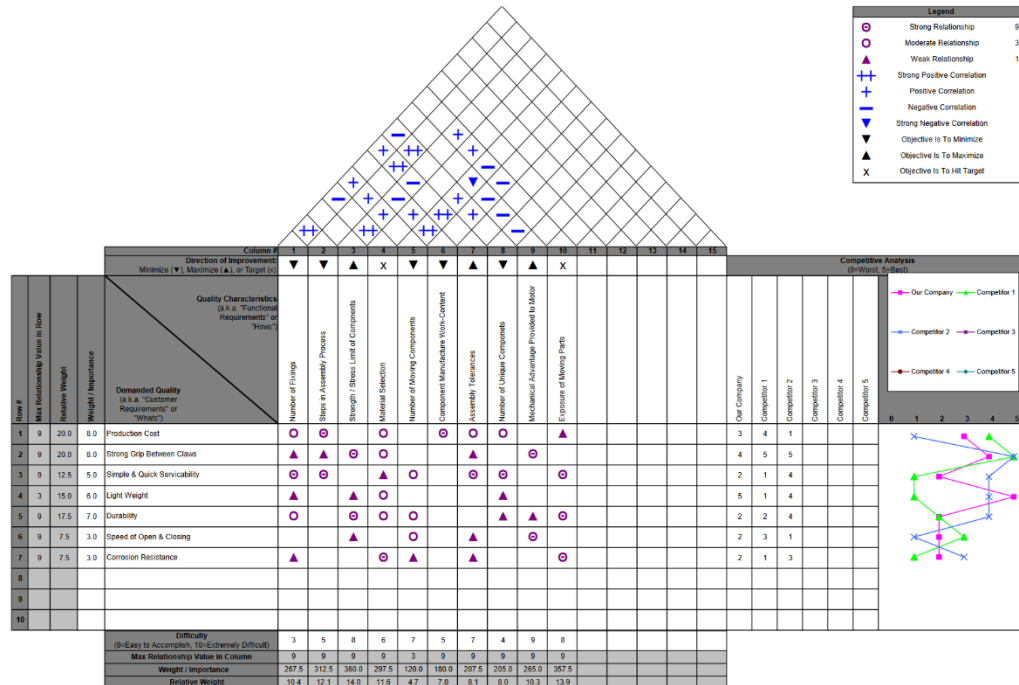


Figure 1 QFD for Robot Gripper Design & Development

Of the factors which are shown in Figure 1, not all are of direct importance. When considering which factors influence the scaling of production, it's important to consider which functional requirements impact the ability of a part to be mass-produced. In this study, factors such as the number of fixings, the complexity of the assembly process and the assembly tolerances have an outsized impact on the manufacturing methods chosen and the ability for a design to be mass-produced. Similarly, functional requirements such as the stress limit or the mechanical advantage provided to the motor don't have an outsized impact on how easily the product can be mass-produced.

Accepting this, the relative weightings provided by the QFD are key to understanding which design elements are important to the customer. It is key to conserve the quality of elements which are heavily 'weighted' or valued by the customer, while improving on the design elements which have an outsized effect on how efficiently the product can be mass-produced. These customer-driven requirements are:

- Stress Limit of Components
- Motor's Mechanical Advantage
- Material Selection

These affect factors such as weight, speed of jaws and corrosion resistance. These factors are important for the customer but not the manufacturer. The goal of any re-design process should be to preserve the quality of these factors. The design specification for this design will focus on changing the properties of design requirements which influence ease of manufacture.

Specification Point	Requirement	Reason	Success Requirement	Desired / Required?
Cost	The cost of the product should not increase. The cost could decrease through improving manufacturing efficiency.	No requirement has been given to reduce or change the cost of the product has been given in the brief	Every change made to the design should be considered to make sure the cost of manufacture isn't increased.	Desired
Assembly Complexity	The complexity of the assembly process should be reduced in order to ready the product for larger-scale production.	The brief states a requirement to increase the volume of production. To achieve this, a reduction of the work content will be needed to bring unit costs down.	The new and old designs should be evaluated using DFA Lucas method techniques & compared. The design efficiency should <u>double as</u> a result of this re-design.	Required
Maintenance	The ease of maintenance of the product shouldn't be affected by any design changes	No requirement has been given to change the ease of maintenance of the product in the brief	The customer must retain the ability through DFM to access and replace the	Desired

	made to the product.		motor and moving components	
Component Manufacturability	Improvements in assembly time and efficiency should not come at the expense of increasing up-stream workload	In order for the product to be increased in production volume, the overall ease of manufacture must be taken into account	Each new / altered component should be considered from a DFM (Design For maintenance) standpoint, and work content should reasonably not be increased.	Required
Grip Strength	Parts which affect the strength / quality or ability of the product to perform its primary function should be unchanged.	The quality of this aspect of the product, as shown in the QFD, is highly rated. The quality of the production should be unaffected by DFA or DFM	The key components related to the motor function of the claws should be untouched, only how they are assembled together.	Desired

Table 1 Robot Gripper Design Specification

2.3 Analytical & Technological Methods Review

Design plays a key role in determining manufacturing costs, with the design influencing a significant portion of manufacturing costs and product quality performance (Taylor, 1997). Design for Manufacturing and Assembly (DFMA) aims to simplify product structures to reduce assembly and total parts costs, emphasizing the importance of design decisions (Giuda et al., 2019). Design for X can be used to improve product cost through assembly and manufacturing efficiency without compromising performance.

Design for X (DfX) methodologies, such as Design for Assembly (DFA) and Design for Manufacture and Assembly (DFMA), play a crucial role in product development by focusing on specific engineering challenges like manufacturability and ease of assembly (Favi et al., 2021). Additionally, DFMA considers downstream processes like manufacturing and assembly right from the design stage, ensuring that products are designed in a way that facilitates these processes (Tan et al., 2020). These methodologies are essential for enhancing simplicity and cost-effectiveness in manufacturing (Daniyan & Mpofu, 2019), in this case for a product with increasing production volumes. The consideration of design and manufacturing concurrently allows the consideration of various criteria beyond product performance, such as production capabilities and support (Pal & Drstvenšek, 2021) which is the central consideration of this project.

Injection moulding is a widely recognized manufacturing process that offers numerous cost benefits. The process is known for its ability to produce uniform, high-quality polymer structures (Liou & Chen, 2005). Injection moulding is preferred over other methods like reaction injection moulding due to its simplicity, shorter cycle times, and ease of operation (Heckele & Schomburg, 2003). For this reason, with increased volumes and the complexity of the part, injection moulding will be the best long-term solution for the manufacture of the plastic jaws. For steel components, while die cutting technology is the best solution for truly high-volume components, laser cutting can be cost-effective for high-volume production runs, laser cutting offers advantages in terms of precision, versatility, and potentially lower maintenance costs over time. Optimization of parameters like cut speed and power can lead to superb quality cuts at low cost and high production rates (Madić et al., 2020).

2.4 Manufacturing Process Proposal

This product, manufactured at approximately 1000 units per week, must be manufactured at an average rate of one unit every 2.4 minutes. The components within the assembly fall into one of three categories:

- Plastic Components
- Sheet Steel
- Fixings (screws, bolts, etc)

The plastic components have very intricate detailing, and material saving design. These features exclude methods such as extrusion, due to the limited geometric variety. Conversely, additive manufacturing techniques cannot support the high volumes required, due to the hours-long manufacturing time per part. Injection moulding, despite the comparatively long setup cost, is the most efficient method. Additionally, as a process, injection moulding will have a lot of potential production capacity.

Sheet steel, or any form of sheet metal, can be cut with a variety of potential methods. In this scenario, methods such as die-cutting, although possible, would represent a significant investment without significant benefit. Instead, for medium volumes such as this, laser cutting can cover the production requirement while offering design and product flexibility further down the product life cycle. Additionally, due to the flexibility of the process, extra investment in tooling isn't required for each component, and laser cutting eliminates tool change times where production has to stop. Removing this change time means the WIP (Work In Progress) stock can be greatly reduced, allowing for just in time manufacturing between the manufacturing of the parts and final assembly.

The fixings used in the assembly will be bought-in from external suppliers. For standardised fixings, the economies of scale available to those suppliers allow them to manufacture those components at prices any in-house process wouldn't be able to compete with.

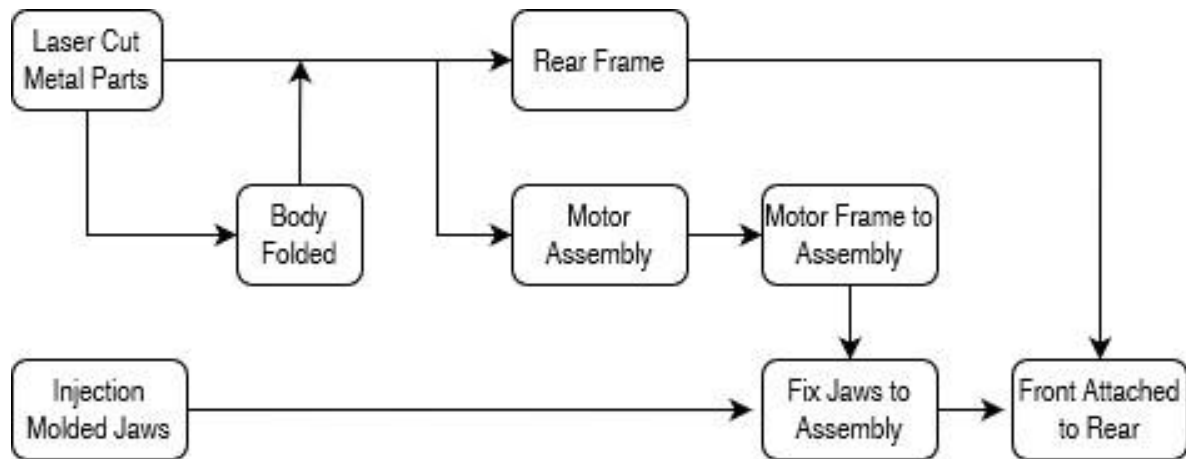


Figure 2 Diagram of Robot Gripper Manufacture Process Focused on Component Material

Figure two shows the different process streams each component type will travel down based on manufacturing needs. The majority of the in-house components are metal and will travel down the path from laser cutting. This highlights the need for flexible and high-capacity metal, and predominantly sheet metal of varying gauges.

2.5 Design and Development

The design efficiency of the original gripper assembly has been calculated in Table two at Approx. 10.5%. This takes into account all individual components within the assembly.

Gripper Final Assembly		
Part	Essential(A)	non-Essential(B)
Part 7 (1)	Y	
Part 6 (1)		Y
Part 8 (2)		Y
Part 3 (1)	Y	
Part 4 (1)		Y
Part 9 (1)	Y	
Part 1 (1)		Y
Part 2 (1)		Y
Part 10 (1)	Y	
Part 10 (2)		Y
Part 3 (2)	Y	
Part 4 (2)		Y
Motor Assy	Y	
44 Fixings		Y x44
Total	6	51
Design Efficiency:		10.53%

Table 2 Original Robot Gripper Design Efficiency Breakdown

In total, there are 58 individual parts within this original final assembly design. 44 of these parts are fixings, which are always targets for design-out. As such, this is the focus of the DFA (Design for Assembly) improvements to this product.

Using SCAMPER and design for assembly principles, this report aims to achieve 25% efficiency. The simplest fixings to be designed out of the assembly are within the frame of the gripper, which is only present for structural support. These elements can be removed with single-piece body designs which fulfil all the same functions. The frame can be broken into two distinct parts, the front and rear.

In order to preserve the form and function of the rear of the frame, this new body will be assembled from two components. These will be formed sheet metal; a material which lends itself to this assembly. Using formed steel components allows the product to maintain the same strength and material composition while eliminating the need for metal components to be fixed together, either through fixings or welding processes. The body must provide support for elements such as the motor/moving components as well. The rear has cross-members and is fixed to the front. These cross-members are presumably to allow the claw to be fixed to other products. They cannot be formed using this process and so will still need to be fitted.

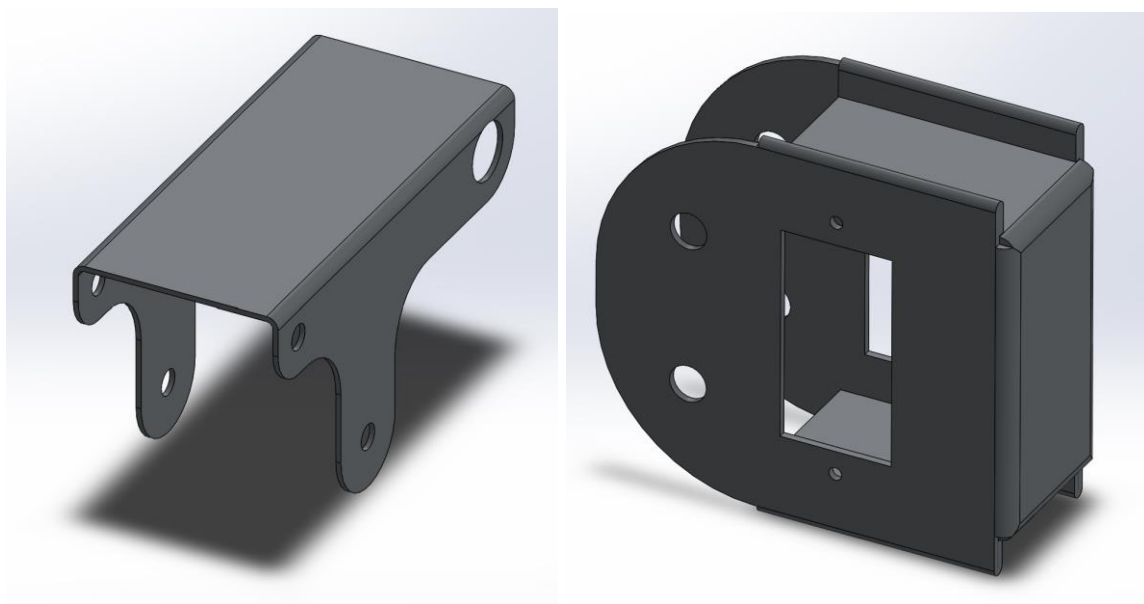


Figure 3 Images of New DFA Optimized Components

The assembly is responsible for the translation of movement from the motor to the jaws and similarly will have minimal changes applied. The bolt jackets can be removed, as they do not contribute to the structural stability of the assembly.

The Jaws will be fitted through a single screw, substituting the dual bolts currently used to fix the jaws to the metal arms. These must be fixed with a semi-permanent fixture in order to preserve the maintenance requirements. Yet, the four fixtures aren't all necessary, and these can be replaced using

a machine screw. The stress on this component is perpendicular to the length of the Jaws, and so the force is transferred through the metal support under the soft jaws.

The machine screw used will be the same as the other machines screws throughout the assembly. This will leave only one type of screw used in the assembly, eliminating the possibility of confusion. Additionally, using only one type of screw will simplify the supply chain for the manufacturer, reducing costs related to delayed suppliers, stock management and administration.

Other maintenance requirements include the serviceability of the motor, and the ability of its removal and possible replacement. Due to this, the motor fixings will be unchanged, which allows the same level of serviceability.

The manufacture of formed steel components is done through two steps, first cut and then formed. These components have clearance designed so that tools used in this process are able to efficiently form the desired component within tolerance. The possible tolerance must be taken into account when re-designing components with new manufacturing techniques.

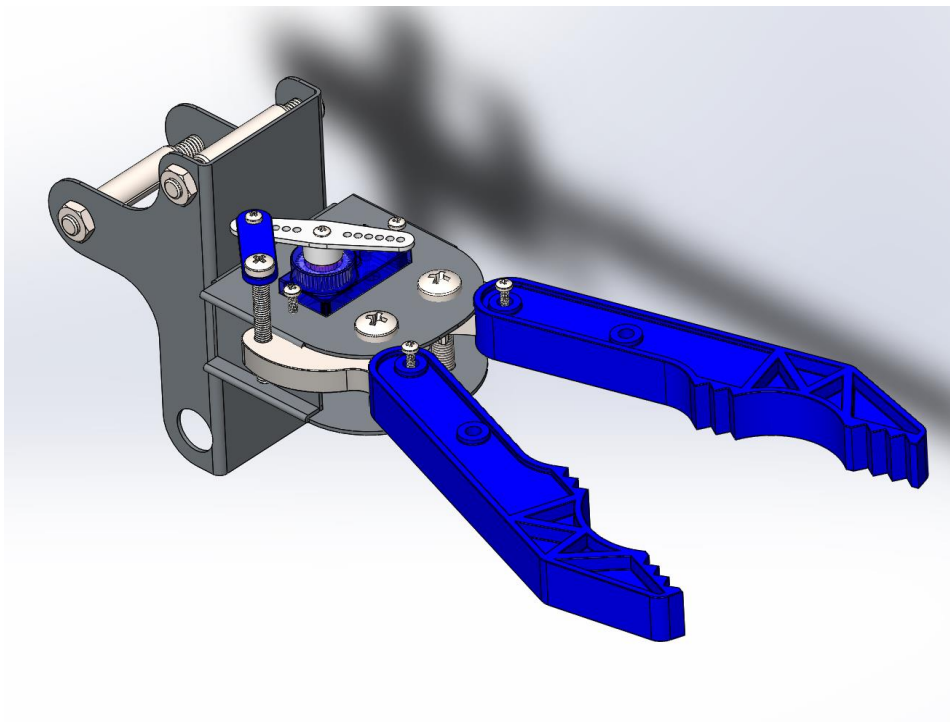


Figure 4 New DFA Optimized Robot Gripper Assembly

Part	Essential(A)	non-Essential(B)
New Body	Y	
New Support		Y
Part 3 (1)	Y	
Part 9 (1)	Y	
Part 2 (1)		Y
Part 10 (1)	Y	
Part 10 (2)		Y
Part 3 (2)	Y	
Motor Assy	Y	
44 Fixings		Y x19
Total	6	22
Design Efficiency:		21.43%

Table 3 Design Efficiency Breakdown of New Gripper Assembly

In the re-developed design, as shown, the design efficiency has had a significant improvement up to 21.43%. This has primarily been achieved through the elimination of 25 fixings from the assembly. Many of these held the body of the gripper together, and have been removed with a single component. Additionally, the plastic jaws of the gripper are now push-fit with the steel underneath. A single machine screw is still present to allow in-service adjustment.

FAILURE MODE AND EFFECTS ANALYSIS														
Item:		Robot Gripper			FMEA number:									
Model:		Redesigned Assembly			Page :									
Core Team:		N/A			FMEA Date (Orig):		31/05/2024		Rev:					
Process Function	Potential Failure Mode	Potential Effect(s) of Failure	S e v	Potential Cause(s)/ Mechanism(s) of Failure	O c c u r	Current Process Controls	D e t e c	R P N	Recommended Action(s)	Action Results				
										Actions Taken	S e v	O c c	D e t	R P N
Closing Gripper Jaws	Jaw Material (Plastic) Degraded	Jaw undergoes plastic deformation around object	2	Age of Component	3	Jaw can be replaced	7	42			2	3	7	42
		Jaw Snaps under stress	6	Age of Component	8	Jaw can be replaced	9	432	Regular Component Inspection	Customer Should be advised to inspect Jaws	6	8	4	192
		Fixings around Jaw fail / get loose	5	Age of Component	6	Jaw can be replaced	3	90			5	6	3	90
	Metal component / Washer corrosion	Jaws are unable to move due to corrosion	8	Water / Dirt Entrapment	7	N/A	4	224	Remove components which might trap water	Washers reduced to single part	8	2	4	64
		Material / Component Failure	7	Water / Dirt Entrapment	5	N/A	2	70	Additional Cover around moving parts	Add Cover around sides of components	5	3	3	45
		Stress on mechanism causes motor failure	6	Corrosion obstructing movement	4	N/A	5	120			6	4	5	120
	Motor Electronics Short / Fail	Gripper Jaws are immobile	8	Electronics Fail	6	N/A	8	384	Easier Access to motor	Reduced number of fixings	8	4	4	128
		Electric Shock due from live components	9	Exposed wire	1	Components are Sealed in Motor Case	3	27			9	1	3	27
	Removal of Fixings for Maintenance	Corroded Fixings	Fixing cannot be removed / replaced	6	Dirt/Water Ingress	4	N/A	4	96	Fewer exposed fixings	Number of Fixings Reduced	3	4	4
		Fixings Fail	7	Dirt/Water Ingress	2	Inbuild Stress Tolerance	2	28						0
	Fixings During Maintenance	Fixings Lost and Cannot Re-assemble product to spec	9	Loss of parts	3	N/A	9	243	Single-body components	body assemblies replaced with single parts	9	3	5	135
		Fixings Incorrectly Fastened and Assembly strength is effected	4	Fixing cross-threaded	7	N/A	8	224	Use other fixing methods	Welds used to replace some fixings	5	3	7	105
								0						0

Table 4 FMEA of Robot Gripper Assembly Before & After

Table four shows the FMEA performed during and after the design process. The failure modes were assessed against the original design, and recommended actions for the worst failure effects were taken forward to the new design. Many of these focused on the benefits of removing the number of fixings within the design to reduce the number of points of failure. Additionally, design faults such as exposed moving components. These actions influenced the design process from a failure and safety point of view.

2.6 Robot Gripper Conclusion

In conclusion to this component of the report, success in a wide area of DfA and other design techniques allowed accurate and targeted changes to be applied to the initial design to boost its manufacturability and design efficiency. These design changes were guided by a QFD to target key design points and to achieve this through specified and relevant technical requirements. These design choices were further guided through analytical techniques which permitted the design to achieve improvements in the technical requirements of the product as efficiently as possible.

A key model this report used to assess the comparative success of a given design was its design efficiency, which was improved by a factor of two. The report also acknowledged that while using this metric as a gauge for the improvement of the assembly design, other factors needed to be considered so that less prioritized aspects aren't ignored to their detriment.

3 Additive Manufacturing Redesign

3.1 Introduction

This section of the report aims to explore technologies associated with the enhancement of design techniques. These advancements with improvements in CAD modelling increasingly inform and influence design choices by substituting traditional design techniques with generative modelling. This, is in combination with an exploration of how this can be used for DfAM. This section will explore generative design and Finite Element Analysis, in conjunction with QFD, a more traditional design technique, and how components designed using these techniques can be optimised for additive manufacturing.

Generative design utilizes algorithms and computational power to explore a vast space of design possibilities, automatically generating optimized structures based on predefined constraints and performance criteria. Finite Element Analysis, on the other hand, is a powerful computational tool used to simulate the physical behaviour of structures under stress and various conditions.

The use of these techniques will be performed against the customer needs of a component as determined through QFD analysis. The final aim therefore is to develop and propose improvements to the design of the product based on these modelling techniques and propose a new form better suited for the component's requirements. The application of these techniques has the potential to greatly accelerate the development process.

The component selected for this study is an injection moulded lock catch for the back of a drawer. The component is designed to clip into a cutout of a steel drawer, taking advantage of injection moulding's ability to form consistent, complex geometry to make the best use of space possible.



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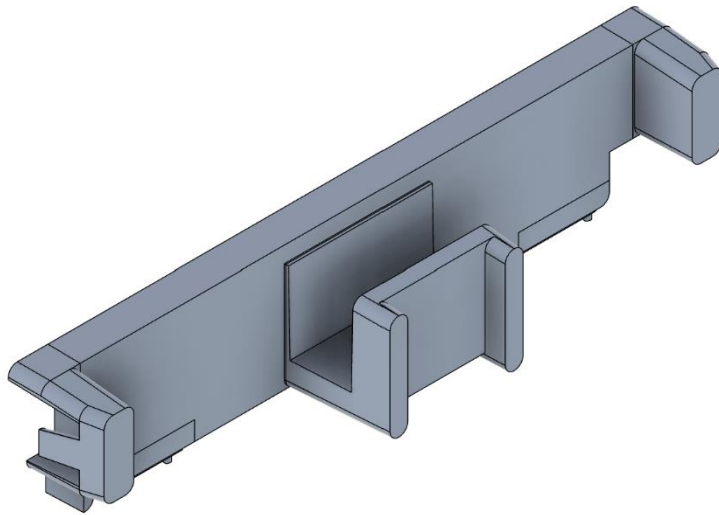


Figure 6 Original Nylon Catch 3D Model

Nylon 12 has high tensile strength when compared to other polymers, and this highlights its suitability for applications prioritising strength, (Shakiba et al., 2021) which lends itself as a suitable material for 3D printing techniques. Additionally, this component needs decent elastic properties, to allow clip-in geometry to function. This component is also currently manufactured in Nylon PA66. Any design focused on strength and additive manufacturing through 3D printing must take into account the effect of the process on stress resistance. Factors such as part orientation, layer height, extrusion width, and nozzle diameter have been identified to affect the ultimate tensile strength and impact toughness of 3D-printed samples (Mazen et al., 2022). However, 3D printing can notably improve the strength of nylon 6-based materials compared to traditional manufacturing methods. For example, the Izod impact strength of 3D printed nylon 6-based blends is much higher than that of injection moulded pristine nylon 6 (Chapman et al., 2020).

3.3 Design Techniques

Quality Function Deployment (QFD) is a systematic methodology in product development to align customer requirements with product design characteristics (Wang et al., 2023). It serves as a tool to convert consumer expectations into actionable steps for enhancing products and services (Dursun & Arslan, 2018). QFD involves translating customer requirements into engineering characteristics, ensuring that the final product meets customer needs (Wang et al., 2016). By integrating the "voices of consumers" into the design process, QFD facilitates the development of products that align closely with customer expectations. This methodology enables the pre-planning of product specifications, process specifications, and production stages to reflect customer requests effectively (Yücenur et al., 2020).

QFD plays a crucial role in quality planning by starting with identifying customer needs and concluding with determining process plans (Zheng & Chin, 2005). It aids in enhancing customer satisfaction by improving product quality and reducing production time and costs (Aghdam et al., 2015). Moreover, QFD has been recognized as a valuable tool for translating customer requirements into engineering characteristics, contributing to innovative product development (Miguel, 2007). The methodology has been heralded as an essential part of the product development process, emphasizing its impact on enhancing life-cycle integration (Vonderembse & Raghunathan, 1997).

Furthermore, QFD has been applied in various industries beyond manufacturing, demonstrating its versatility and effectiveness in addressing operational decisions and supplier selection problems (Asadabadi, 2014). The methodology has also found applications in services and eco-design, showcasing its adaptability across different domains (Gwangwava, 2013; SivadasAniyan & Pramod, 2018). Overall, QFD remains a valuable approach for organizations seeking to align their products and services with customer needs and expectations, ultimately driving quality improvement and customer satisfaction.

3.4 QFD Assessment

The QFD has been used to track the needs and the quality characteristics of the component ready for development through this report. The function of the component is to catch a lock bar at the rear of the unit, to prevent the drawers from opening when locked, and to be an easy push-fit design as an improvement upon previous designs requiring separate fixings or assembly operations such as welding. As well as being an easy fit during final assembly, this push-fit needs to be able to share the strain from the catch. The strength of the catch is additionally important to prevent the component from becoming loose and potentially working its way free.

The catch has the most fundamental requirement of being strong enough to resist any reasonable attempt to prise open the drawer while locked. Due to the material being a nylon plastic, and any attempt to force the drawer inevitably puts strain on the lock bar and catch, in most scenarios, this is the first component to fail. This material was selected for two main characteristics. First, nylon is a slightly flexible injection-mouldable plastic, which lends itself to this type of push-fit design. Secondly, plastics are a highly cost-effective material regardless of manufacturing method, with the key difference being the manufacturing process time.

Other factors are the weight and aesthetics of the component. Due to the size, material, colour and function of the component, these factors are minimal compared to other requirements of the component.

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Table 5 QFD of Nylon Catch for Design & Development

In order to achieve these customer (or in this case some production) needs, several functional requirements need to be balanced. The key aspects of these requirements are the balance of reducing the used material in order to make the component lighter and more cost-effective, and adding material in the right locations to maximise the strength and durability of the catch. Highlighted by the QFD is the strength of the push-fit detail over the strength of the catch. This is due to its influence on both the

strength of the component and the ergonomic fit at the final assembly stage. As both of these factors are concentrated in a single area, the importance of getting that design element correct is out-sizes compared to other elements. The material choice is also highlighted as an area of focus, however, the material will remain the same through this development and so isn't relevant to the development of the component.

Conversely, the means of manufacture, and the exact method of stress distribution are weighted low against these other points. These areas will be focused on sparingly through this process. Additionally, this component is already manufactured through an injection moulding process. The exploration of additive manufacturing techniques for this component will be the focus of any DfM (Design for Manufacturing).

When considering generative design, the aesthetics of the results will also need to be considered, although to a lesser extent since the relative weight of this aspect is almost half of the more important customer needs. Generative designs often have unique and irregular geometry which might conflict with the aesthetic requirement for this type of product.

3.5 Finite Element Analysis

The original design of the push-fit catch was subjected to a FEA, or Finite Element Analysis. It involves dividing a complex system into smaller, simpler elements to facilitate analysis. The method allows for the prediction of how a part or assembly will perform under specific conditions (Ozcan & Ersoy, 2021).

The push-fit catch has had an FEA applied to it with the aim of better understanding the component's reaction to being put under realistic stress conditions. The inside face of the catch had 100N (over kg of force) applied to it uniformly. Additionally, the entire component was put under nominal strain from gravity from the correct orientation. These stresses work on the component, which is fixed by the contact faces inside each of the four push-fit feet. The stresses shown are under these conditions for a nylon 12 plastic material.

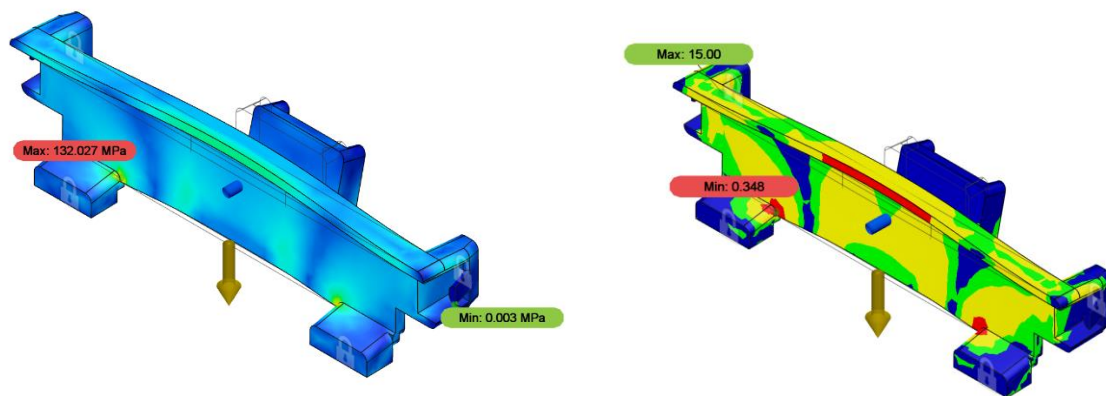


Figure 7 FEA of Original Nylon Catch 3D Model using Nylon-12

As shown in Figure seven, as the component is currently designed, there is in general, little amount of stress across the body. This lack of stress in many areas shows potential for cost saving through material reduction and therefore an overall decrease in production costs. Additionally, there are stress points in the corners of features in the part, as highlighted in Figure seven, where the pressure on the material would, in this model, exceed the yield point of the plastic, causing permanent deformation or tears in the material.

In addition to this highlighted weak spot, other factors might affect how the component reacts to stress. FEA cannot simulate faults, or impurities in the material which can weaken the part. Corners in moulded components, such as this example, can suffer faults in the moulding process which might artificially weaken the component; and as such the area might give way sooner than anticipated.

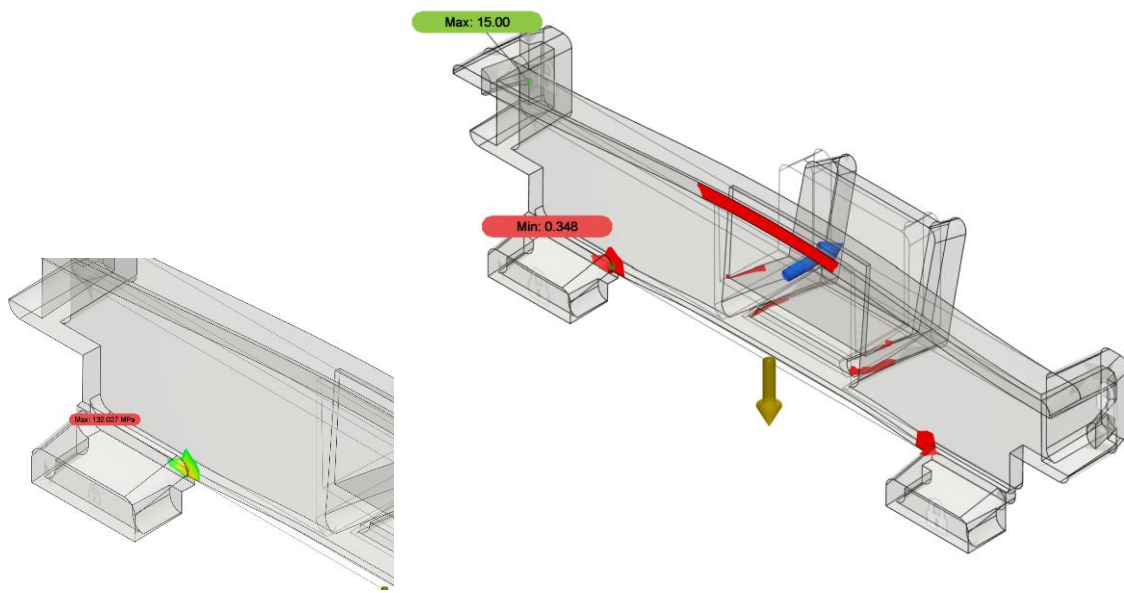


Figure 8 FEA Material Failure Points on Nylon Catch

The material supporting the catch was also found to not be sufficient to reliably support the forces applied to the component. At higher stress levels the component is liable to fracture in the places indicated in Figure eight. These models indicate that any form of design work needs to focus on reinforcing these points with additional material in order to prevent failure. When doing this, focus should also be placed on the other identified quality characteristics found in the QFD, such as the amount of material that should be minimised, and the effect these changes have on manufacture time in an additive process. The cons of these need to be effectively balanced, in relation to their importance, with the requirement to effectively distribute stress across the structure.

These goals should be achieved by the informed removal of material from areas which don't experience major stress applied to them. The material removal will aim to improve the ability for these components to be manufactured through an additive process, due to the reduction in time and material per-part.

3.6 Generative Design

Moving on from the FEA of this initial component, the key elements of the design were translated into generative software in order to explore the potential results from generative design tools. These designs used the determined forces acting on the component to attempt to optimise the component for material usage and strength. In order to simulate this, the programme used the known theoretical properties of nylon 12 in the modelling process, which has an average yield stress of 46.6MPa (MatWeb Material Property Data, 2022).

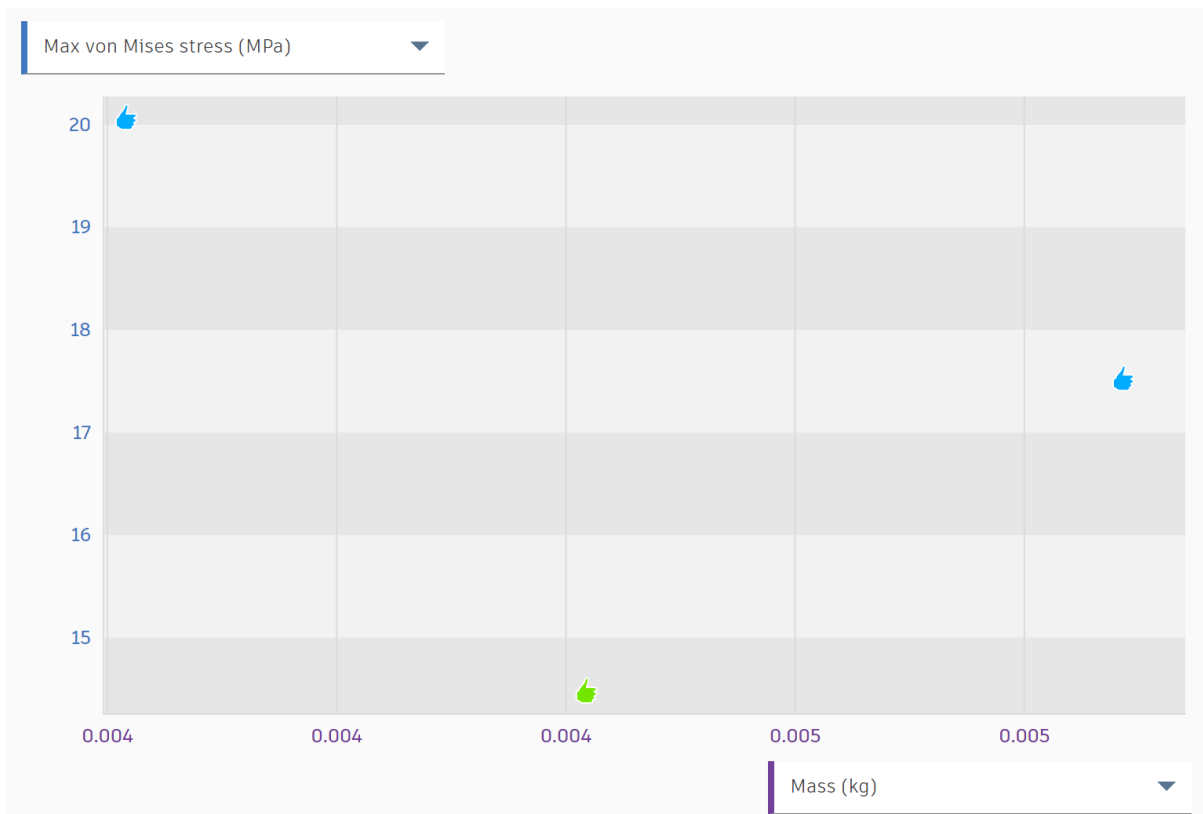


Figure 9 Stress and Mass Plot of Generative Design Results

The three results are shown in Figure nine, in which the design which has been ultimately moved forward is highlighted in green. This design has a middling mass relative to the other options, however has the lowest stress peak, at 15MPa, than any of the other options (20MPa and 17.5MPa respectively). All of these are well below the 46.6MPa yield point of the material, which is a major improvement from the original design which majorly exceeded it at corners and other centres of concentrated stress. Due to this, and the average amount of material used, this was selected as the design choice to move forward with.

In this configuration, assuming the accuracy of the model, this component could withstand up to 3.3 times greater force than in its previous form. This allows the component to have a comfortable margin for any defects in the manufacturing process, or shocks outside of that which is in the specification.

However, this large safety margin implies that material, and therefore cost over the mass-production life-span of this product, could be comfortably reduced while leaving a comfortable margin of safety.

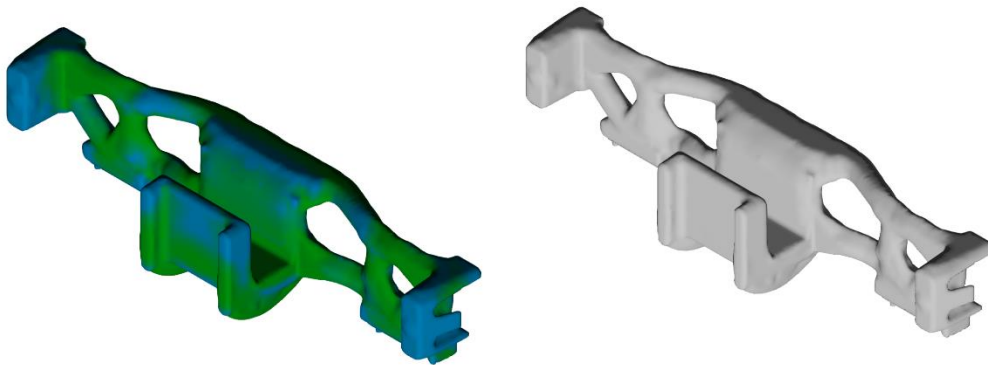


Figure 10 Generative Design Final Result

The result of this generative design process is shown. The elements important to the function have been isolated so as not to be altered so that the structure of these components are unaffected by the generative process.

As shown in Figure 10, the spread of the stress across the body of the component. This has been achieved with the removal and addition of material by the computer based on how the component is loaded. Some material under no stress being left in the component is unavoidable, as some parts, such as the push-fit pins and the catch. These details have been left from the original design, as they perform functions related to the quality of the push-fit in addition to the material mass and stress distribution. Additionally, the converged design settled on by the algorithm still has some elements of the design which aren't under equal stress, which shows how elements of the frame might be able to be improved upon.



Figure 11 3D Printed Prototype using Generative Design Model

A prototype was manufactured using additive techniques. This proved the ability of the component to be successfully manufactured in such a way, and the accuracy of that process in replicating the model with its intricate design features. A key consideration for further prototyping will be the effect of 3D printing on the yield characteristics of the component. 3D printed components have an inherent weakness when stress is applied perpendicular to the layers making the part.

Importantly, the time to manufacture this component through additive manufacturing techniques is significantly reduced from traditional means. To manufacture this component at a suitable scale, a massive investment in infrastructure would need to be in place to keep up with demand. The key advantage to exploit in this situation would be the customisability and design flexibility after production begins. To fully leverage this, no monolithic design would be used, but custom designs for each product type and exact use case would need to be formatted and exploited, allowing for design improvement on the fly.

3.7 Additive Manufacturing Conclusion

In conclusion, this section has assessed a production component's core requirements, and used these requirements to create aimed improvements to its design through analytical and digital techniques. These requirements were successfully translated through the use of QFD and the 'customer voice' intrinsic to understanding and applying technical requirements. This project identified the key needs and improved upon these technical areas through digital design methods including FEA and generative design. These techniques were guided towards the improvement of these identified key areas.

This section could have met additional success through blending these more minor considerations such as new methods of achieving a push-fit. More traditional design methods could be blended with more detailed analyses of push-fit geometry to achieve measurable improvement in these areas while not compromising the overall strength or material use. In future studies, initial manual re-design, as achieved in the previous section, should be used after the application of digital tools. The application of these together will provide the best possible design outcome; an outcome in which development with these tools individually would require a high investment to achieve complex results.

Additionally, the high volume this product needs to be manufactured in might prove this manufacturing method unsuitable. However, the design converged upon in this study has a good chance of being able to be injection moulded, which would pose a significantly cheaper capital and skills-based investment to implement.

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