

Design and Assembly optimisation

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Design and assembly optimization
For COM1 letterbox manufactured by
SAFETY LETTERBOX COMPANY Ltd.



Major Project

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'This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has lead to the award of the degree.'

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Abstract

The project documents and presents the result of investigation of COM1 letterbox designed and manufacture by Safety Letterbox Company. This project aims to determine whether the changes in the geometry of the extrusion components or improving adapted production procedures will bring the total cost reduction for the company.

As the report pursue to cost reduction of producing the COM1 product different methods and tools are used. In order to create the base for the analysis was conducting two practical test in the workshop. The first was tensile test which just confirmed that the created joint is stronger than the aluminium. The second, was a destructive test which helped to visualize the damage to the part when 900N force is applied.

The calculated force was applied in FEA simulation in order to compare the result especially for AMC-985 part, as proposed changes for the design reduced the mass of the part by 13%. Interesting result from the simulation is that the current design for SAL -501 is 48% less resistant to deflection than the proposed AMC-985. In addition these two parts belongs to the front surface of the COM1 and can equally be exposed to different kind of external forces. So the company need to justify the required mechanical properties for the COM1 product.

Considering, mass reduction as one of the stated objectives in the report, the final result of proposed changes could reduce the mass of COM1 by 3.5%. However, along with proposed changes the project investigate how that will affect the current manufacturing processes used and assembly procedures applied. Based on evaluated drawings in SolidWorks it was possible to calculate the difference in cost for the extrusion and recycled material, between the current and proposed designee. Knowing that the SLB supply the aluminium extrusion parts and approximate cost of the material is £3.50 per kilogram the company could potentially save 5% considering only extruded parts needed to assembled one COM1.

The answer is given in the second part of the project were the Lean-Sigma Manufacturing methodology is used. The analysis is based on data-driven improvement cycle DMAIC applied for production processes adapted by the company. The tools used are DFA which defined the design efficiency index which shows that adopted process in the company is efficient.

The second tool used is PFMEA which prioritized area with higher risk of failure such as the quantity of produced scrap poor standardization, poor control of the process.

1 Introduction

The Safety Letterbox Comnay (SLB Company) is a leading UK's manufacturer of secure mail and parcel delivery boxes existing on the market for over 34 years. In 2012 the company become a part of the RENZ Group a German company which holds a preeminent position across Europe. The Managing Director of SLB, Alison Orrells said that *'it is a very positive step forward ... straightening both our excellent market position here and supporting our international growth'* [1].

The relation between those two companies can be described as a collaborative benchmarking. Veen-Berk et al. [2], in their report defined it as a relation based on sharing their ideas towards design and manufacturing processes used, inventions and future plans. One of the positive outcomes from this partnership for SLB Company is introducing to the British market an intelligent parcel boxes what is a significant progress.

Although company's offer consist of 130 different mailboxes this report concentrated only on one of their product, that is to say COM1 depicted on Figure 1. The customer can choose different solutions for ordered products such as

Fire Rated Mailboxes where product must conform to BS476 Part 6&7 [3] which requires testing materials in order to define if it is a flammable material, and Part 22 which examine the structure of the mailbox if 'will maintain its integrity for one hour'. The second solution is called a Security by Design, is a crime prevent technique initiate by the police in 2016. The first meeting with the company was arranged in a late August in 2018 when the company proposed the project and their expectation. The Manufacturing Manager Keith Jones was delegated to supervise the project. The official cooperation started from visiting the warehouse, and introducing to the assembly and manufacturing processed adapted by the company.

The first part of the project concentrated on investigating the design of COM1 product. Mainly the product is assembled from aluminium extrusions supplied by Hydro Company. The Manufacturing manager provided technical drawings as well as helped with identifying all features and their function. The analysis was performed using Finite Element Analysis (FEA) simulation in SolidWorks, and based on the result the changes to the design has been proposed. Based on FEA simulation the mass reduction of every part was estimated as well as the capacity of recycled aluminium.

The second part of the report is focused on Lean Six Sigma DMAIC approach is used to assess the current manufacturing processes used and assembly procedures applied. And provide a systematic and logical approach to the problem. The DMAIC stands for Define,

Measure Analyse, Improve, Control. The model provides a systematic and logical approach to the problem.

The current mechanism implemented by the SLB is a pull system which in lean manufacturing controls the production flow of materials. Many sources unequivocally suggested that the 'pull system' is the most profitable for most businesses. The 'pull system' in contrary to 'push system' focus the production on the actual demand and consequently provide ability to hold relatively small inventories. Also as Ulewicz et al. [4] described, it reduces the total cost of a production and all decisions are made on regular basis. The mechanism used by the company is 'Kanban' a Japanese word which means 'signalling device'.

2 Aims of the project

The aim of the project is to reduce the mass of one of SLB Company products a COM1 letterbox depicted on Figure 1 and consequently reduce the total cost of a production. However, it beg a valid question is it only one area where the company can save money without scarifying the quality of the product?

It is known that product reliability is strongly correlated with the customer satisfaction and product quality and cost reduction are key factors in the present competitive market. For that reason a second objective is to investigate manufacturing processes used and assembly procedures applied.

In order to demonstrate the achievement of the stated aims this project focused on;

- Mechanical and manufacturing properties of material used.
- Manufacturing processes used such as bending, extrusion and welding.
- Interpretation of current technical drawings of extruded parts.
- Manufacturing and assembly consideration with economic involved in design changes
- Proposal for changes of COM1 design based on FEA simulation. The purpose of the simulation is to investigate mechanical properties of the parts mainly resistance to fracture and deflection.
- Proposal for continuous improvements based on DMAIC methodology.

As the analysis was limited amount of information about the cost, capacity of recycled material. For this reason the assumptions were made and they are explained further in the report.

Current design for COM1 letterbox

The e information about the product has been provided by the company.

- Suitable for both domestic and commercial use
- Suitable for internal and external installation
- Materials used; extruded aluminium 6063 T6 and stainless steel
- Available in three configurations; A4, A3, Lateral
- Complies with Secured by Design guide for standardization
- RAL colours



Figure 1. COM1 letterbox manufactured by SLB Company.

Envelope mail boxes	1	2	3	4	5	6	standard configuration 3x6 COM1
	2						
	3						
Parcel mail boxes	1		2		3		1 by 3 COM1 for parcels

The provisional structure installation offered by the company is pictured on figure 2. The structure consider maximum three COM letterboxes in vertical direction.

Figure 2 One of the offer form SLB Company. The structure 3 x 6 mail boxes and 1x 3 Parcel boxes.

3 The literature review

Material properties and manufacturing processes needed to build the COM1 product are described below with concentration on techniques types chosen by the company.

3.1 Mechanical properties of AA6063-T6

When designing the product a company need consider the main purpose of the product and customer requirements. The SLB Company have chosen aluminium extrusion parts to manufacture their product. The Extruded parts are supplied from Hydro Extrusion Company which uses AA 6063-T6. The table below present different alloys used for extrusion.

Table 1 Mechanical properties comparison of Aluminium Alloy used for extrusion process.

	2024-T4	5052-H32	6063-T6	6105-T5	7075-T6
Density (g/cc)	2.78	2.68	2.70	2.69	2.81
Modulus of Elasticity (GPa)	73.1	70.3	68.9	69.0	71.7
Tensile Yield Strength (MPa)	324	193	214	260	503
Fatigue Strength (MPa)	138	117	68.9	95	159
Poisson's Ratio	0.33	0.33	0.33	0.33	0.33

Properties of Aluminium 6063 T6

1. Aluminium Alloys (AA) used in extrusion process are typically the 6xxx aluminium series
2. AA for 6xxx group can be strengthened by heat treatment process followed by rapid cooling then aging (precipitation) process.
3. **T6 Solution** means that the AA was heat –treated and artificially aged. Applies to product that are reheated to a low temperature following a solution treatment. This allows the metal to achieve its highest heat-treated strength level.
4. **Lightweight** property makes a perfect material choice for the company
5. **Flexibility** is the indicator property for the extrusion companies as it is extremely malleable what means that any shape can be created. Hydro Company [5] increases the temperature up to 500°C to force the aluminium ingot though the die creating a final product. The die design depend on the technical drawings provided by the customer, in this case SLB Company.
6. **Corrosion resistant** in variety of environments what create an important factor for COM1 product as it can be installed externally. Prillhofer et al. [6] conducted an intergranular corrosion testing for 6xxx alloy group and simulated paint bake treatment, AA 6063 T6 shown no corrosion attack, comparing to AA 6013 T6 corrosion depth was 350 µm.

As soon as metal is exposed to the atmosphere a self-protecting, transparent oxide film is formed at the surface.

7. **High strength to weight ratio.**
8. Stiffness of the part can be designed what means the geometry of the part define the resistant do deflection. Also considering that extrusion process gives ability to produce almost any shape the stiffness of the product can be design by changing the design but necessarily adding material.
9. It is a sustainable and fully recyclable material. However any further treatment in favour of the desired final product reduce the verity of recyclability.
10. It is a **weldable** material. COM1 is joined by using a tungsten inert gas (TIG) welding
11. It is an example of ductile materials with an extensive plastic deformation and energy absorption before fracture.
12. Aluminium alloys are used in various cryogenic (low-temperature) applications as the material get much stronger when the temperature drops.

3.2 Manufacturing processes used

Extrusion

Extrusion as one of industrial deformation in processes can be carried out in many different ways. Groover [7] classified types depending on direction forward and backward extrusion also called direct and indirect extrusion.

Second type depend on the working temperature hot and cold extrusion. The

graphical representation of direct, hot extrusion used by Hydro Company is depicted on the Figure 3. Firstly the feedstock: aluminium billet is heated up to 500°C in the furnace. Next step is to load the billet into container where is compressed and forced through die. Heated metal losses its strength what makes it more ductile what helps to create complex and integral profiles.

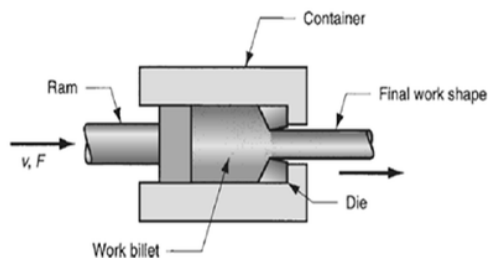


Figure 3 Graphical representation of direct extrusion process.

Extrusion process is associated with standard BS EN 755-2:2008 [8] which specified requirements for the profile and acceptable mechanical property limits and that is the reason why the design is rejected in an early stage of the design process.

Different organisation such as The Aluminium Extruders Council (AEC) [9] or Elixir Industries [10] gives an instruction for successful extrusion designs as well as common mistake and how to avoid them.

1. Tolerances

Extrusion process has ability to hold tight tolerances. However that advantage can create limitation for instance when the designer does not have knowledge about dimensional limitation. Also, wrong tolerances can gain additional cost for the customer what in lean manufacturing is treated as a one of the Ohno's 7 wastes. For that reason important is consultation of the design with Extrusion Company. The concept used by Hydro Company 'You bring your ideas to us, and we begin to discuss your requirements ...' [5] as the technical resources of extrusion company need to be considered.

2. Suitable for various joining methods.

AEC [9] defined different kind method of joining shown on Figure 4, of aluminium extrusions with different material. In addition extruded parts can simplify the assembly process by combining integral connection points. These benefits can help to save time and reduce the cost.

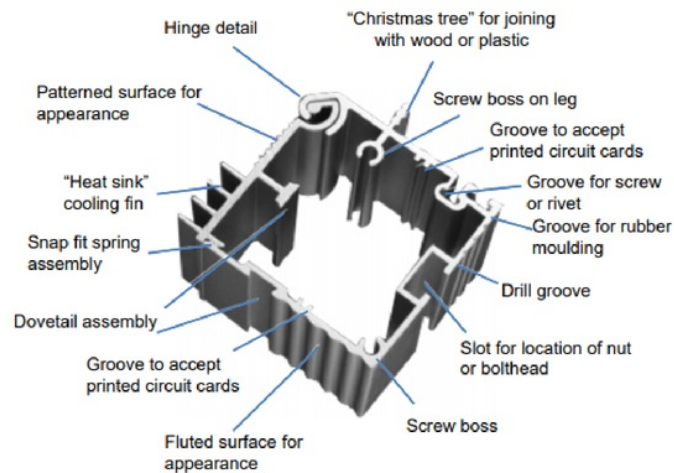


Figure 4. Aluminium extrusion joining methods.

3. Proposal of good design practises.

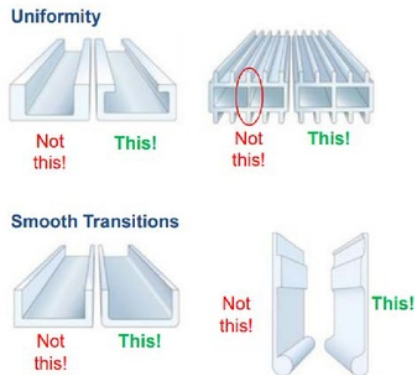


Figure 5 Good design practices proposed by AEC.

The performance of the product can be tailored by the designer. That is to say to the designer by implement stiffeners in places where reinforcement is needed creates resistance to deflection required. Uniform quality of the design is very important. Engineers adapted many rules, some of them are presented on the Figure 5.

Bending

One of the most common sheet-metal forming process used in the industry is bending. It brings many advantages to the manufacturing process for instance, very often can replace joining several parts what helps to produce a uniform product. Nevertheless in order to make a high quality product, important is to understand the process and mechanical properties of working material as it affects the deformation behaviour of sheet metal under bending forming.

During the process the outer fibres of the material are in tension while inner are in compression.

Kalpakistan and Shmid [11] defined the criteria of bendability of the material

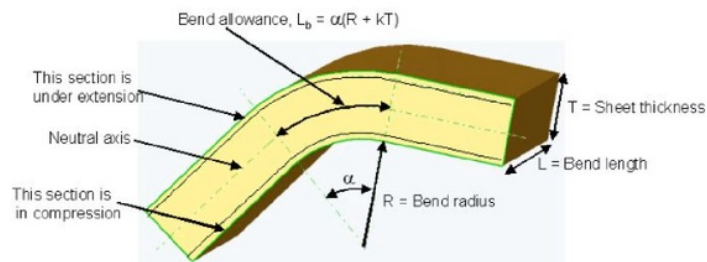


Figure 6. Bending process.

- The thickness of the plate indicate the minimum bend radius. For instance for aluminium alloys in room temperature the radius is equal $6T$ what means the smallest radius must be six times the thickness of the plate to avoid cracks.

- Importance of quality of the edge and the surface. The roughness of the edge or uneven surface of the plate are areas of highest stress concentration. In different word a poor quality decreases bendability of the metal.

- Anisotropy defines different properties of a material depending on the fibres (inclusions) orientation.

Anisotropic characteristic of a material induced by cold rolling improves plastic

deformability of the plate. What does it mean? If the metal is bend parallel to the rolling direction, the material will crack as it can be seen on the Figure 7. So the conclusion arise, knowing that there is a risk of earlier initiation and propagation of cracks the bending line should be placed perpendicular to the rolling direction. Morawinski and Koncada [12] investigated the problem and propose using 3D digital microscope which helped evaluate the limiting parameters for the bending operation.

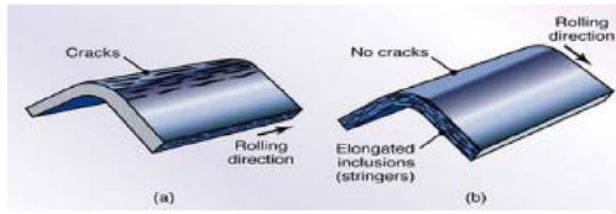


Figure 7. The effect on elongated inclusions on cracking as a function of the direction of bending with respect to the original rolling direction of the plate.

However, engineers need to consider situations where the part can be bend against the rule to prevent cracks. Hence necessary is to study the behaviour of the material or consider a substitute, for instance different process or redesign the part.

Welding

Welding is an example of process where two minimum two parts are permanently joined. As different materials with different properties consist of different capability to be welded into structure with required characteristics and quality, different methods have been utilized for instance friction stir welding, metal inert gas welding, laser welding and ultrasonic welding. Often the process is facilitated with filler material also called metal rod and the joined parts are called a weldment.

The process can be classified into groups;

1. Fusion welding operation where the heat is applied so the joint materials can melt and finally, consolidate. Depending on the type used filler metal is added to the molten pool to facilitate the process. Examples of used welding processes in the industry are; arc welding, laser-beam welding, electron beam welding.
2. Solid-State welding in contrary to fusion welding does not require filler metals and molten phase. As Kalapkijan [11] described the process as a two surfaces in contact under one of required parameters such as pressure heat relative interfacial movement to form a bond

and produce joint. Common processes used are; cold welding, diffusion welding, friction welding, ultrasonic welding.

A person responsible for the quality of weldments should comply with requirements such as awareness of safety standards, good knowledge on metallurgy and different welding techniques as used equipment and tools. Also less obvious qualifications such as concentration and detail orientation.

By reason of comprehensive area of welding process the paper will concentrate only on the process used by SLB Company that is to say gas tungsten-arc welding (GTAW) also known as tungsten inert gas (TIG). This process can be used for variety materials such as steel magnesium and more importantly, for aluminium. The main characteristics of the joint produced by GTAW is a very good strength and reliability. It is good for manufacture larger part and reasonably easy for the inspection. The process require a metal filler similar to the welded metals, the shielding gas mostly argon

– used by the SLB, helium or the mixture of both. During operation the tungsten electrode is maintained in a stable gap with the welded surface at a constant current level. The literature provides different types of fillet joints, that is to say bead, fillet, plug or slot and groove, depicted on the Figure 8. Types used by the company are corner joint for aluminium body shell and spot joints.

As many different processes used in the industry created welds with errors also called discontinuities. For that reason weld joints need an internal and external quality control depending on the requirements. In general the external defects such as under-filling, undercutting and overlap require only a visual quality also define the weld profile especially strength and appearance of the weld.

However internal defect need much more complex quality control. For instance Bakker [13] in his study used X-ray topographic analysis to detect any internal discontinuities such as porosity, slag inclusions, incomplete fusion and penetration.

The quality of the mainly depend on the skills and knowledge of the operator especially for the aluminium. The main rule is to prepare the material to be joined that is to say the edges of the

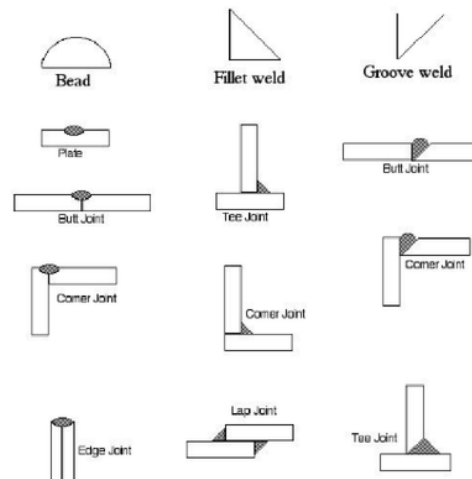


Figure 8. Types of fillet welds

metal need to be carefully cleaned as contaminated surface cause the porosity in the welds. Practically, experienced welder can detected the defect at the beginning of the process.

Lean-Sigma Manufacturing Tools

In current dynamism of the market Lean Six Sigma is treated as a strategic tool to gain efficiency, reduce cost, remain high standards and still satisfy customers. As Enso stated [14] in most cases adopting continuous improvements might be a difficult process especially for small businesses with long term habits. However if the company's desire is to reduce the cost, it must start thinking 'out of box' not only for the product but as well procedures and standards used during manufacturing processes.

Six sigma is the most popular quality and process improvement methodology which strives for elimination of defects in the process. Perfection is defined as goal of continuous improvement and can be approach by a 'zero waste preproduction.

The literature refers to seven basis wastes defined by Ohno. They represent activities that customer is not prepared to pay, so it should be eliminate.

1. The waste of overproduction

Bicheno [15] quoted Ohno's definition of the overproduction as a 'making too much, too early or just in case'. It should be eliminated as it causes other wastes such as inventory, to many operators and the company need to pay first and wait to customer place the order.

2. The waste of waiting

This type of waste is defined as a problem with assembly operation flow. The reason of that distortion can be lack of experienced operators, breakdown of machines, unprepared workstation or required parts for assembly what means that the operators need to wait for the additional instructions, inspections or material to be fabricated.

3. The waste of necessary motion

The next waste concentrate on unnecessary movement of the operator. That include ergonomic design of the workstation what can be explained by questions such as is the layout is efficient?, Does the operator have easy access to needed tools or parts? To solve that problems companies introduced a shadow boards or by introducing a tool used in lean manufacturing '5S' what means Sort, Simplify, Scan, Standardise, Sustain

4. The waste of transporting

Simply, define the distance the operator need to go to handle the part. The transport is simultaneously connected with the communication, what can negatively affect the quality of the product. The recipe for that can be reorganization of whole organization, for instance departments closely such as production line and production manager office should be place close to each other.

5. The waste over-processing (or inappropriate processing)

This waste consist of over-engineering of the product and consequently the manufacturing processes and assembly. This type of waste include information about the efficiency of the used machines or process. Also refers to the quality of the product as if the machine produce parts which required more inspection that could be sign for inappropriate processing. More over the order of the used manufacturing process or machines is efficient or the 'production line need to be re-designed.

6. The waste of unnecessary Inventory.

Sowards [16] said that the organization should keep *'enough inventory on hand to keep the work flowing, but not so much inventory that it has to be stored, protected, counted and moved'*.

7. The waste of defect

Defect cause low quality products, rework and scrap what cost the business money and lost reputation. The example can be incorrect fabrication and assembly the parts or product.

Value of the product is measured by what the customer is prepared to pay for. In Lean manufacturing are;

- Value Added Activities (VAA) for which the customer is prepared to pay. Nallusamy and Ahamed [17] referred to definition of VAA as a 'workplace methodology which helps for improving working environment, human capabilities and thereby increasing productivity'.

- Non-Value Added Activities (NVA) for instance overproduction/over-processing, correction rework, excess inventory, excess motion, transportation and waiting. Lean manufacturing seeks to identify all NVA task and eliminate them as they are defined as 'Muda' that is waste. Also NVA increase the cost of a product without changing the functionality.

The tools (methodology) used to investigate manufacturing process.

Process Failure Mode Analysis (PFMA)

Failure mode effect analysis for process and design refer to errors or potential risk of failure by assigning the severity, occurrence of the failure and difficulty of detection by current control techniques adapted by the company. As the design was investigated in the first part of the project FMEA for the process (PFMEA) has been chosen for further investigation. Very often in manufacturing environment, PFMEA methodology is used to satisfy specified quality standard demand. In many cases a product design analysis is used to determine failure modes for PFMEA. The goal of implementing this tool is either to reduce the chance of occurrence in order to make the process more robust and justify current process of detecting the failure. In general it helps to prioritize countermeasures to reduce errors, what consequently can reduce the cost and time needed to develop the product.

The outcome of PFMEA should be a plan of how to control the process by proposing different types of mechanism for instance monitoring, standardization introducing reports etc. However this tool cannot be used as a final solution for the problem. The reason is that calculated Risk priority Number (RPN) is questioned as it is not a reliable indicator. For instance, for RPN equal 100, when $S=10$, $O=10$, $D=1$ or $S=1$, $O=10$ and $D=10$. As it can be seen the RPN is the same for two cases so it can be assumed that they are evenly important. But they are not as the first scenario presents the very important and severe problem and easy to detect where second shows failure which can be ignored and also is difficult to detect. So the person responsible for the conducting the PFMEA need to justify.

Design for Manufacturing and Assembly (DFMA)

DFMA allows the whole design team in a manufacturing company to understand the products assembly sequences and material flow early in the design process. This result in the development of simple, reliable and easy manufacture products which are less expensive to produce. Harlalka et al. [18], by applying DFMA methodology to investigate a food processor reduced the total cost per product by 1.59% what in longer period of time could make the business more profitable.

The DFMA methodology is divided into design for Assembly (DFA) and Design for Manufacturing (DFM). The main methodologies widely used throughout many different

companies; 'Boothroyd Dewhurst System', 'Lucas DFA Methodology' and Hitachi 'Assemblability Evolution Method' [19].

To assist the project DFA methodology is used to investigate the assembly process for COM1 later in the report. It is a conceptual methodology driven by economical consideration to pursue changes and continuous improvement. The Boothroyd Dewhurst method provides a quantitative measurement called the design efficiency (equation 1) based on analysis of a product. The efficiency compares the total assembly time for the product with the total assembly time for an ideal product determined by a method suggested by the authors.

Devidas and Ahad [20] used different tools to measure design efficiency for Nokia phone. The result was that by using Lucas method the design efficiency was improved by 6 % and by calculating Boothroyd DFA index were able to improve the design by 3%.

Favi et al. [21] investigated decision-making strategies for DFMA in contrast to Design for the Cost and stated that improvements are brought about two consideration.

1. The estimation of time taken for each step in the assembly.
2. A decision need to be made as any part can be eliminate or combined with other parts of the assembly.

4 Analysis of the design COM1 letterbox

4.1 Workshop sessions

Session 1 – tensile test

Experimental procedures

Mainly the reason of the test was to establish mechanical properties of the material used and quality of the weld. The information about the strength of the material in comparison to the weld joint was used in further analysis of the product.

Material used for the test was AA 6063-T6 provided by The SLB Company also mainly that material is used to build COM1 product. The two parts of recycled aluminium were welded by the operator who was responsible for the process and weld quality of every letterbox made in the company. The test took place in one of the workshop at university and the experimental equipment used was a tensile test machine. Before the test the piece of metal was cut in four equal in dimensions stripes. The dimensions of the specimen are provided in the Table 2, the individual test specimens were mounted in the clamps as demonstrated on Figure 9. During test the specimen with uniform cross section area was subjected to increasing load until fracture occurred. The data from each test were recorded on PC-based data system and subsequently used to develop the force versus displacement graph pictured on Figure 10. Also, for every sample the elastic modulus and ultimate tensile strength were obtained. Collected data is presented in the Table 2.



Figure 9. Workshop session 1. Installing aluminium specimen into tensile testing machine.

Experimental result

As it can be seen on the Figure 10, investigated pieces of aluminium fractured in very similar manner, just above the weld joint. Also the second conclusion is that the weld is stronger than the AA 6063-T6.

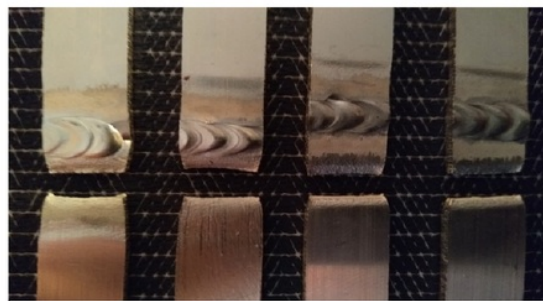


Figure 10. Workshop session 1. Samples of aluminium after tensile test.

The surface of the fracture define the elasticity of a material. As it was mentioned before aluminium represents a ductile material called where the fracture morphology is called 'cup and cone' shape and occurs when shear plane will occur at 45° in respect to stress plane.

Table 2 Mechanical properties of Aluminium 6063-T6 in tensile test.

Measurements	Aluminium 6063 T-6				
Original length, L [m]	0.318 m				
Cross section area, A [m ²]	0.0025m x 0.012m = 0.03 x 10⁻³ m²				
Young's modulus [Pa]	70-80 x10 ⁹ Pa				
Tested specimens;	Specimen 1 'Weld 1'	Specimen 2 'Weld 2'	Specimen 3 'Weld 3'	Specimen 4 'Weld 4'	Average
Force[N] Limit of elasticity	2625 N	2645 N	2890 N	2890 N	2763 N
Displacement [mm]	1.39 mm	1.39 mm	1.56 mm	1.56 mm	1.48mm
Stress [N/m ²]	87.50x 10⁶	88.17 x10⁶	96.33 x 10⁶	96.33 x 10⁶	92.1 x 10⁶
Strain [-]	4.37x 10⁻³	4.37x 10⁻³	4.91x 10⁻³	4.91x 10⁻³	4.65x 10⁻³
Young's modulus [Pa]	19.98 x 10⁹	20.18 x10⁹	19.62 x10⁹	19.62 x10⁹	19.83 x10⁹
Ultimate Tensile Strength (UTS)	3945 N	3780 N	4045 N	4045 N	3954 N
Elongation [mm]	3.75	3.41	4.09	4.09	3.84

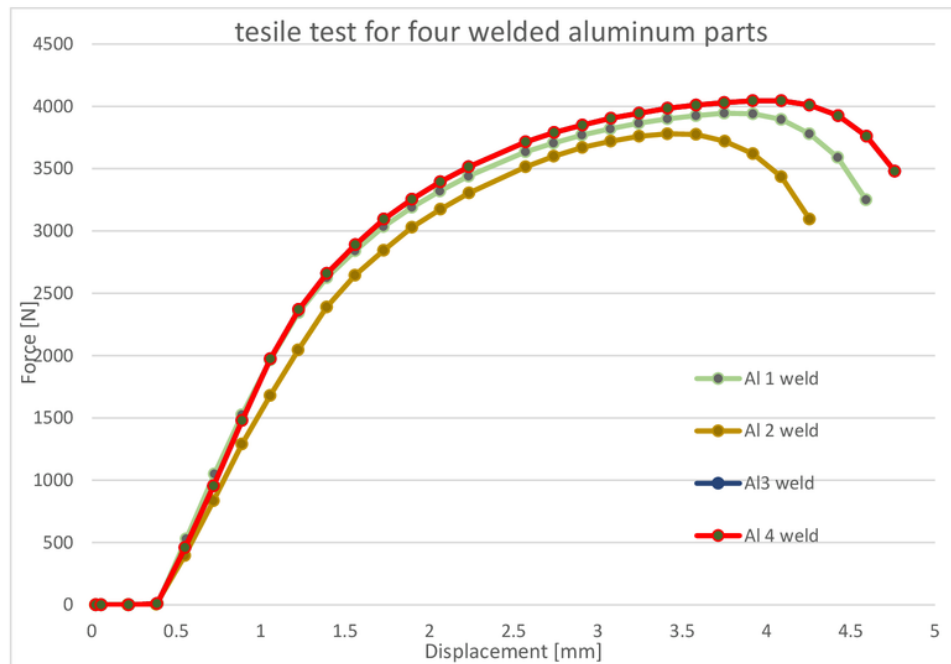


Figure 11 Workshop session 1. Tensile test on Aluminium parts welded in order to quantify the strength of the weld vs the material.

The outcome from the test for four specimens was very similar. The average of maximum force applied before necking was 3954 N. The limit of elasticity for the material occurred at force 2890N caused a 1.59 mm displacement.

However for better understanding the data it need to be considered a few aspect such as;

1. Regarding welding process described earlier, the influence of welding differs depending on operator's skills, cooling process applied, the parameters employed etc. Having that information and knowing that the specimen, for that particular test, was cooled down mechanically in order to accelerate the process it can be assumed that the weld is stronger when produced for parts ordered by customers. Likewise Nguyen at el. [22] In his report 'approved' the assumption they sated that *'the weld joints are always stronger than the base metals in both tensile strength and surface shape of weld joints'*.

2. Also as Menzemer at el. [23] revealed in his study that AA 6063 after artificial aging or heat treatment mechanical strength of the material increased. Also their observed negative consequences of the heat applied during welding called heat-affected zone (HAZ), decreased the strength of the material compering to specimen without the joint. As it can be seen on Figures 10, 12, how close to weld the fracture occurred.

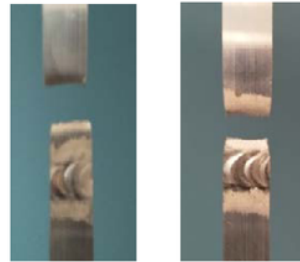


Figure 12. Workshop session 1. Samples of aluminium after tensile test. Two examples of fractured

Session 2 – destructive test.

The destructive test was performed on extruded parts used to build COM1 product. The machine used is depicted on the Figure 13, was provided by the university. In order to measure the energy required to fracture and stiffness of a part a load is applied suddenly on the area of the part where the stress is highly concentrated. Zammit [24] also stated that the amount energy required to break the part is taken as a measure of the resistance to fracture. Also define the stiffness of the part as the property can be designed by implementing reinforcement features to the design. More information can be found in the section where the extrusion process is explained.

In order to calculate the force exerted on the extruded part, the body of mass 5 kg was mounted 1 metre above the investigated part. The process consider the Principle of the Conservation of Energy. What means when the body freely fell and strike the part '*loses its potential energy and gain kinetic energy equal to original potential energy, when no external work is done on a body*' [24]. Hence,

$$PE = KE$$

$$mgh = \frac{1}{2}mv^2$$

Where 'v' is the velocity of the body at the point of impact with investigated part.

$$v = \sqrt{(2gh)}$$

$$v = 4.43 \text{ m/s}$$

$$KE \text{ gained} = PE \text{ lost}$$

$$KE = 49 \text{ J}$$

Further calculations used a work energy principle which establish the net work done during the impact is equal to the difference between final and initial kinetic energy. So if P.E. given up on the body is equal gained K.E., the lost potential energy is equal work done on aluminium part. Assumption was made that the distance moved of the mass after impact, 'd' was approximately 50 mm. Hence

$$PE \text{ lost} = WD \text{ on the aluminium part}$$



Figure 13 Workshop session 2. Machine used for the test.



Figure 14. Workshop session 2. Destructive testing on body shell - AMC-716.

$$mgh = Fd$$

$$F = \frac{mgh}{d} = \frac{49 \text{ J}}{0.05 \text{ m}}$$

$F = 980 \text{ N}$ - Force exerted on metal

The above equations used for the calculation were sourced from Zammit [24] book.

Calculations revealed the force exerted on the aluminium extruded parts tested in this session is equal 980 N.

Despite the fact that the force is known, it need to be consider as an assumption as the variable 'd' was defined by the operator not measured. The estimation was based on study made by company PCB [25] which produces instrumentation used by predictive maintenance professionals to test, monitor and control the processes such as impact or dropping test machines. In the study the dropped mass was 4.5 kg from 1 m height and for the stainless steel distanced moved was equal 0.0005 mm, so knowing that aluminium is much softer material the estimation for the this report was for $d=0.05\text{mm}$.

The result of the test is depicted on the Figures 15. As it can be seen the higher deflection occurred on the AMC-730. The reason could be that, only that part has not be strengthened by future as, for instance AMC-985. Having the information that form manufacturing manager that the company has not recorded any damages due to poor design, weak structure or violence acts the question could be asked what stiffness of a product is required.

The benefit of the destructive testing process mentioned by PCB [25] was that *'it might be used to validate designs on prototype to ensure they meet durability and safety requirements'*.



AMC-716



AMC-730



Figure 15. Destructive test result for AMC-985

4.2 Current and proposed designs for COM1parts.

1. SLB Extrusion

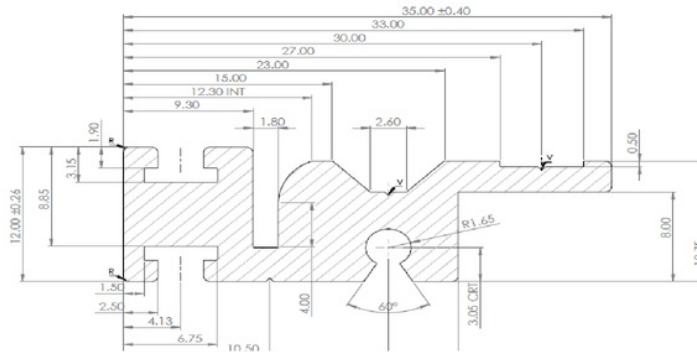


Figure 16 Technical drawing of SLB extrusion part. (Re-designed in Solid Works by the author of the report)

Table 3. The mass of the part for all configurations available.

Configuration	Length	Mass	
	[mm]	[g]	[kg]
A4	235	144.13	0.1441
A3	310	190.13	0.1901
LATERAL	330	202.40	0.2024

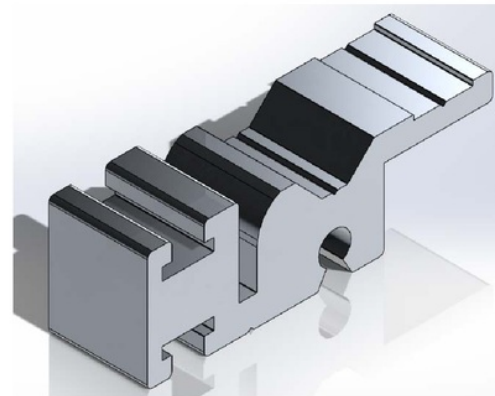


Figure 17. Isometric view of SLB extrusion part. (design by SLB Ltd. And re-design elaborated by the author of the report in SolidWorks).

The component depicted on the Figure 16, 17, does not belong to COM1 letterbox design. However it is part from which the installation is build (mounted). As it can be seen above on technical drawing shows a very small dimension and all feature have their function for that reason no changes were implemented. The current design was redesigned in SolidWorks. In addition the mass of the part for all advertised configuration is defined in Table 3.

1. AMC 765

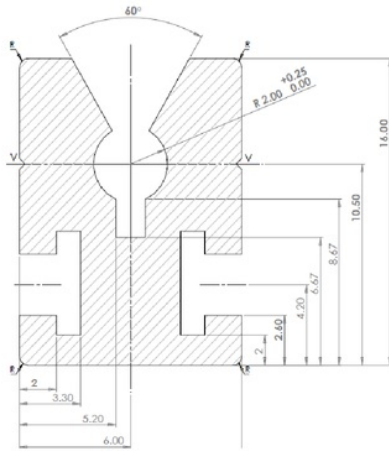


Figure 19. Technical drawing of AMC 765.

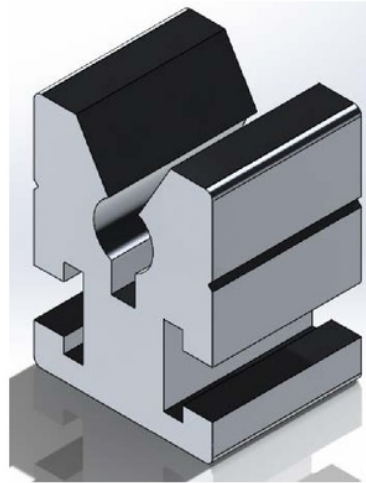


Figure 18 Isometric view of aluminium, AMC-765. (SLB design elaborated by the author of the report in SolidWorks).

Table 4. Physical properties of the part for configurations advertised by the company. The measurements represent difference between mass of current and re-designed part.

Configuration	Length	Mass Current design		Reduction of 'VEE' features	Mass reduction/addition
	[mm]	[g]	[kg]	[kg]	[kg]
A4	235	84.73	0.0847	0.0849	+0.0002
A3	310	111.77	0.1118	0.1120	+0.0002
LATERAL	330	118.98	0.1190	0.1192	+0.0002
Mass addition by					+ 0.2 %

AMC-765 depicted on the Figure 18, 19, the same as SLB extrusion part does not belong to the COM1 product assembly and also is a part of the installation. The company has stated a guidelines for compulsory changes for the product, that is to say the reduction of the 'vee' grooves form the front surface as their only one function was aesthetics. Finally the change increased the mass of AMC-765 by 0.2%.

AMC-780

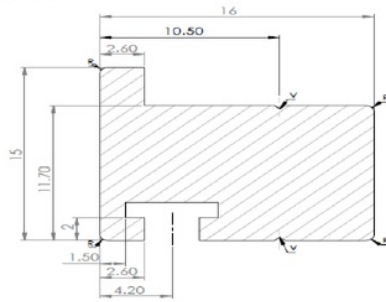


Figure 21. Technical drawing of AMC 780.

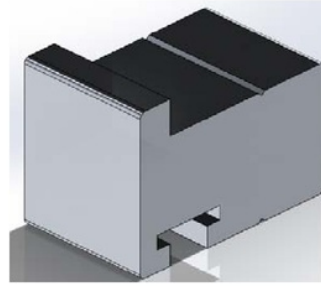


Figure 20. . Isometric view of AMC-780.
(SLB design elaborated by the author of the report in SolidWorks).

Table 5. Physical properties of the AMC-780 for configurations advertised by the company. The measurements represent difference between mass of current and changed design.

Configuration	Length	Mass For current design		Reduction of 'VEE' features from front wall	Mass reduction /addition
	[mm]	[g]	[kg]	[kg]	[kg]
A4	235	115.29	0.1153	0.1155	+0.0002
A3	310	152.08	0.1521	0.1523	+0.0002
LATERAL	330	161.89	0.1619	0.1623	+0.0004

Table 6 Design proposals for AMC-780 with interpretation how the design changes affect the strength of the part.

Design Proposals for AMC-780	1	2	3	4
Configurations				
A4	(-) 0.0333	(-) 0.0167	(-) 0.0197	(-) 0.0165
A3	(-) 0.0440	(-) 0.0219	(-) 0.0260	(-) 0.0218
LATERAL	(-) 0.0468	(-) 0.0233	(-) 0.0277	(-) 0.0252
Mass addition/reduction	-29%	-14%	-17%	-13 %
Strength addition/reduction	-23%	-5.7%	0 %	0%

AMC-780 part depicted on the Figure 20, 21 is used by the company to build the construction for COM1 to be mounted in required space. The cross section area of the part is approximately 190mm^2 , from such a small surface area is difficult to reduce the mass without scarifying the strength. Table 6, consist of four different designs for AMC-780 and it can be seen how changes in the geometry can affect the performance of the component.

In order to predict the influence of changes introduced to the design Finite Element Analysis (FEA) simulation was used for the current design and proposal number '4' from Table 6,, the result of FEA is depicted on the Figures below. The input data for two parts was the same, that is to say the mesh size; 0.7mm and force 900N, the variable calculated from impact test.

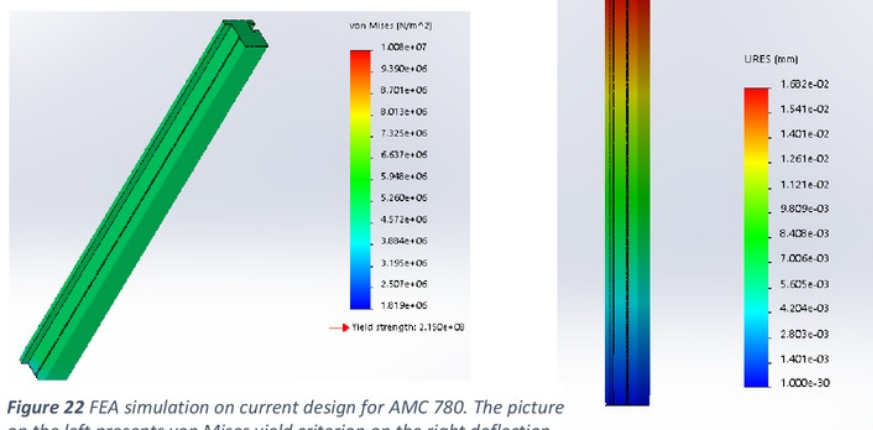


Figure 22 FEA simulation on current design for AMC 780. The picture on the left presents von Mises yield criterion on the right deflection.

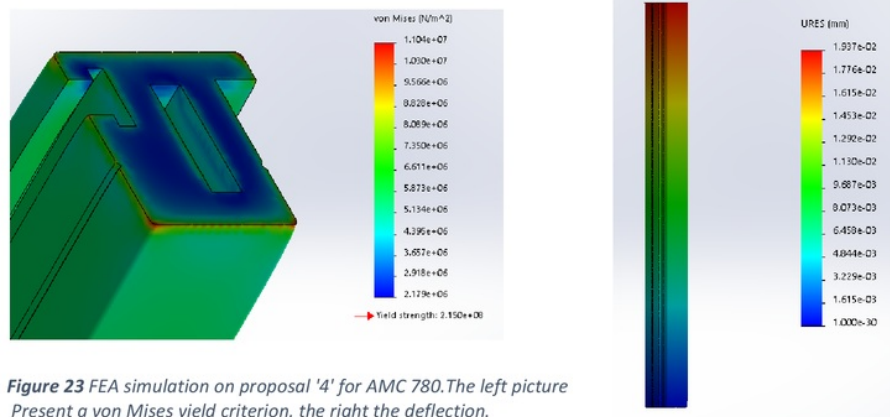


Figure 23 FEA simulation on proposal '4' for AMC 780. The left picture Present a von Mises yield criterion, the right the deflection.

The result of simulation for the strength suggest that the strength of the designs was the same. However the resistance to deflection decreased by 0.255mm what means that the stiffness of the proposed design decreased by 15%. However the company has no provided information about the design and procedures applied for the installation it is difficult to justify the negative affect of the change of the AMC-780.

AMC-730 – small flap

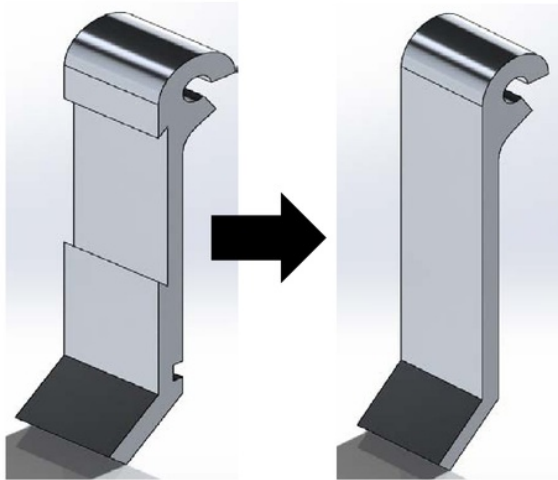


Figure 25. Isometric view of, AMC-730. On the left current design and on the right a proposal are shown (SLB design elaborated by the author of the report in SolidWorks).

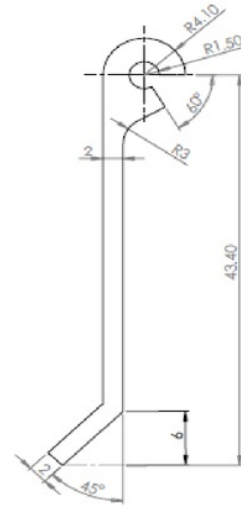


Figure 24. Technical drawing of AMC-730

Table 7. Physical properties of AMC-730 forgiven configurations. The data represents difference between the current and proposed design.

Configuration	Length	Mass		Re-designed part	Mass reduction/addition
	[mm]	[g]	[kg]	[kg]	[kg]
A4	234	81.57	0.0816	0.0804	- 0.0012
A3	309	107.71	0.1077	0.1061	- 0.0016
LATERAL	329	114.68	0.1147	0.1130	- 0.0017
Mass reduction by					-1.5 %

Current design for AMC-730 'small flap' depicted on the left side of the Figure 25, is one of the parts of the COM1 letterbox, assembled to horizontal body shell part by using a hinge connection. It creates an access for the envelopes. The proposed changes in the geometry are shown on the right on the Figure 25. The data for the physical properties of AMC-730 obtained are gathered in Table 7. As it can be seen the result of the modification was a mass reduction by 1.5%.

The FEA simulation was applied in order to validate the mechanical properties of the part. The important input data used was applied force 900N, the same as for AMC-780 in perpendicular

direction to the front surface area. The reason was that the width of the part is only 47mm so it is more likely that the COM1 product could be damage by the applying force to the top surface of COM1 in downward direction.

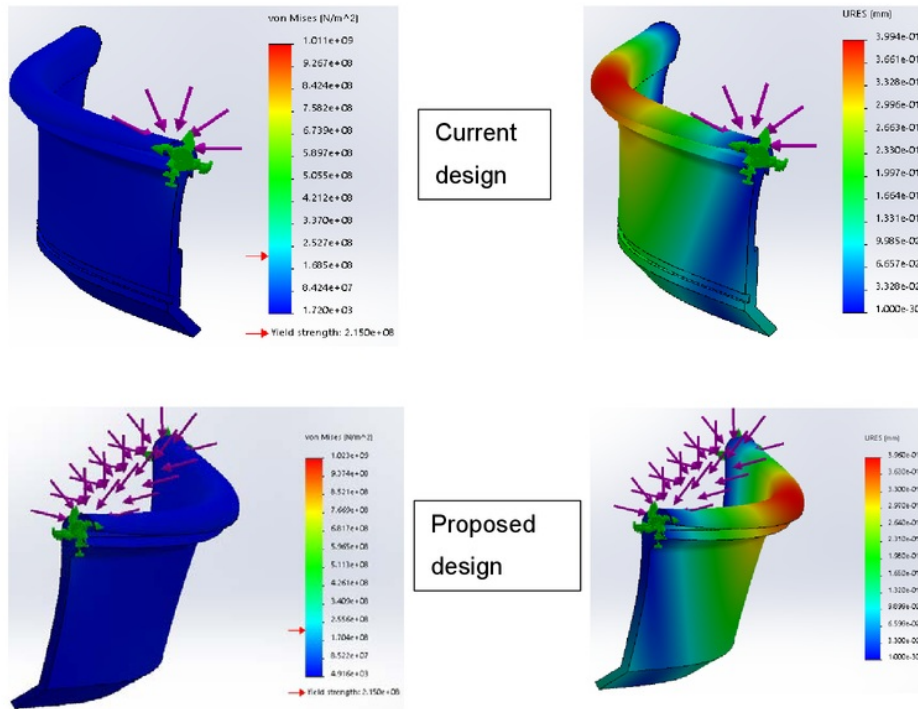


Figure 26. FEA simulation for AM- 780. On the left is presented the change in strength, on the right the change in deflection.

As shown on the figure above the adjustment to the design did not change the mechanical properties of the AMC-780. The resistance to deflection and fracture remain more or less on the same level.

SAL-501 – large door

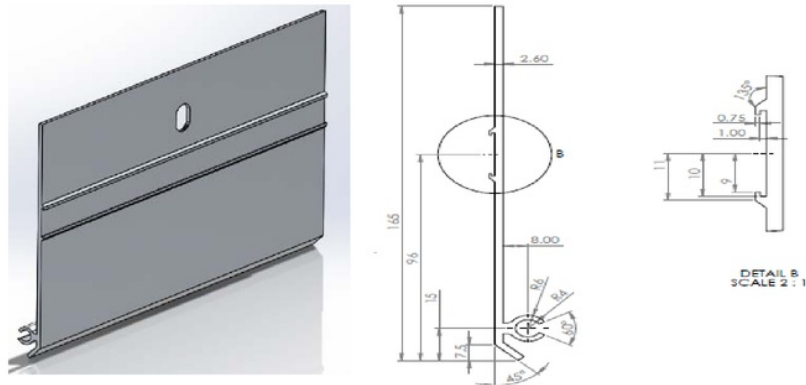


Figure 27. Isometric view of SAL-501 on the left and profile of the part on the right.

Table 8. Physical properties of AMC-730 forgiven configurations. The data represents difference between the current and proposed design.

Configuration	Length	Mass	
	[mm]	[g]	[kg]
A4	231	313.98	0.3140
A3	306	416.52	0.4165
LATERAL	326	443.86	0.4439

SAL-501 is an aluminium extrusion depicted on the Figure above. The main function of the large door is a secured access for the customer to collect the content of the letterbox. The component can rotate so the part is assembled with the body shell by using a hinge system. No changes has been proposed for the SAL-501 as the geometry complies with functionality of the part.

The FEA method was used to simulate the behaviour of the part under applied force. Assuming that the large door was closed the geometry was fixed on the edge as it shown on the Figure 28, and 900N force was applied to the front surface.

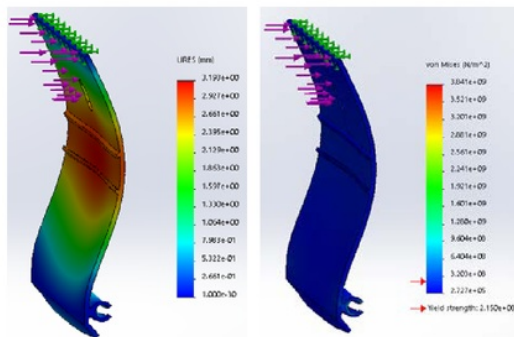


Figure 28. FEA simulation for SAL-501

AMC-716 - Body shell

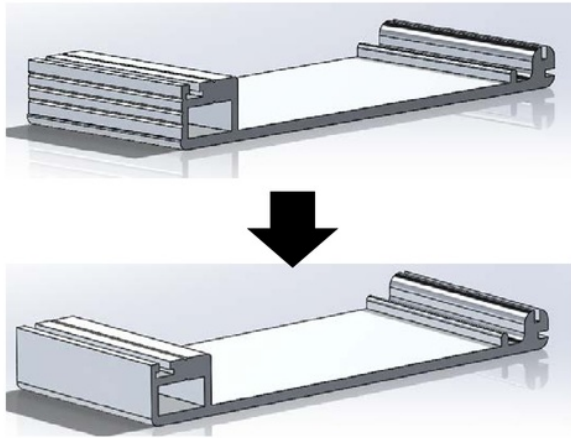


Figure 30 Isometric view of, AMC-716. The current design and proposal. (Design elaborated by the author of the report in SolidWorks).

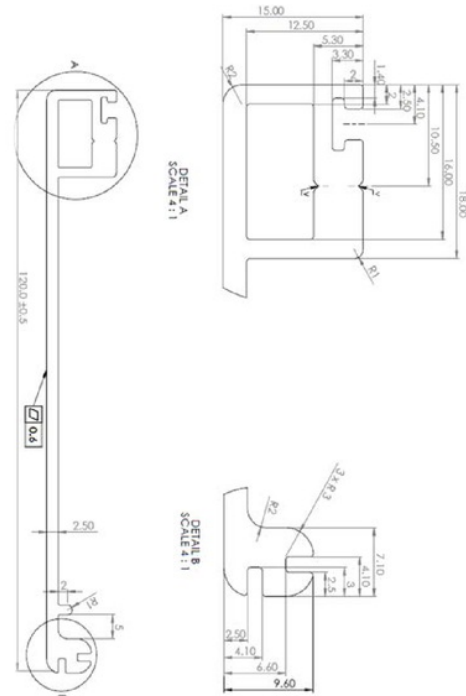


Figure 29. Technical drawing for AMC-716

Table 9. Physical properties of AMC-716 for given configurations. The data represent the difference between the current and proposed design.

Configuration	Width	Mass		Re-designed part
	[mm]	[g]	[kg]	
A4	265	312.46	0.313	0.313
A3	340	403.60	0.404	0.404
LATERAL	360	427.91	0.428	0.429
Mass reduction by				0%

AMC-780 extrusion is used to build the body shell of the COM1 letterbox by using a welding process described in more details in a previous chapter. The only change introduced to the part was to reduction 'vee' grooves features form the front surface as shown on Figure 30. Despite the changes in the geometry the mass remained the same. The reason was that the change decreased the length of the part by 0.5mm, were the COM1 geometry require 120 +/- 0.5 mm in length, as shown on figure 29. The Manufacturing Manager of SLB Company advised that the length must be the same.

Despite the fact the changes did not affect the mechanical properties of the part the FEA simulation was conducted, the result is presented on the Figures below. In order to build the body shell for COM1 four parts AMC-716 are welded, two 265 mm welded horizontally and two 336mm welded vertically.

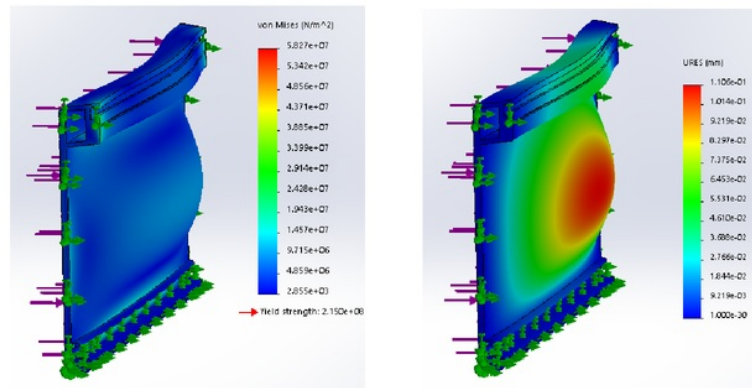


Figure 31. FEA simulation for horizontal AMC-716.

Applied force of 900N vertically and horizontally to AMC-719 did not fracture. The resistant to fracture of a part vertically is almost 45% lower than horizontally but the vertical part is stiffer. Although the properties of the part in different position were different, the strong construction is assembled when they are joined.

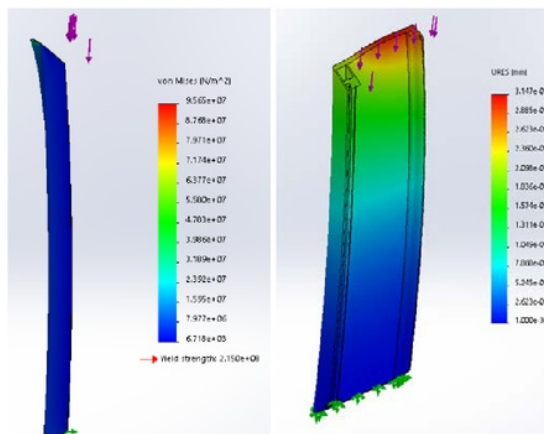


Figure 32. FEA simulation for vertical AMC-716.

AMC 985 – large bridge

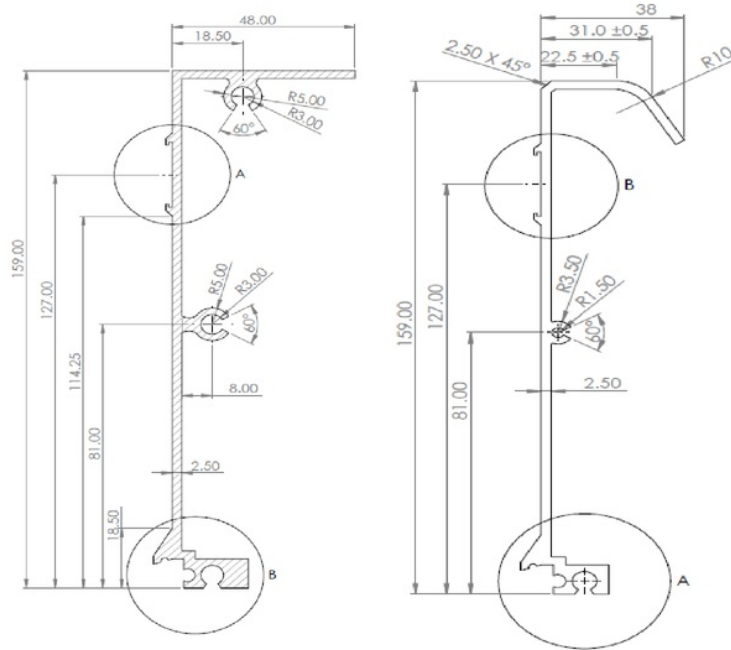


Figure 33. Technical drawing for AMC- 985 for current and proposed designed.

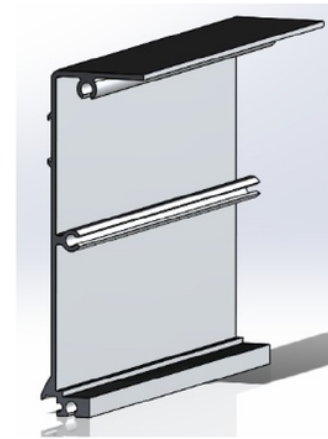


Figure 34. Isometric view of, AMC-985 (Design elaborated by the author of the report in SolidWorks).

Table 10. Physical properties of AMC-985 for given configurations. The data represent the difference between the current and proposed design.

Configuration	length	Mass		Re-design	Mass reduction/addition
	[mm]	[g]	[kg]	[kg]	[kg]
A4	235	473.45	0.474	0.392	-0.082
A3	310	624.56	0.625	0.517	-0.108
LATERAL	330	664.85	0.665	0.550	-0.115
Mass reduction by					13%

Aluminum extrusion AMC-985 depicted on the Figs 33, 34, is a part of COM1 product. It is a fixed component assembled to the body shell frame. After consultation with the company all features with their functions were defined. Based on gathered information the proposed changes included reduction of the reinforcement feature from the anti-fishing element surface. The reason of applying the 'support' in that area was that the surface fractured during the banding process (the process is explained in more details in the previous section). Second

adjustment was to change the geometry of the second reinforcement in the middle of the back surface. Overall the mass of the part was reduced by 13%.

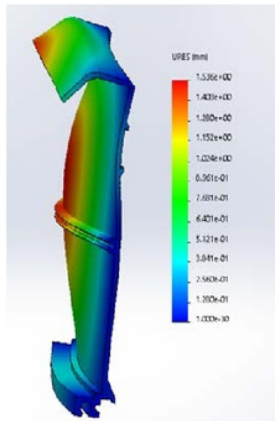


Figure 36 FEA simulation for AMC-985 for the proposal.

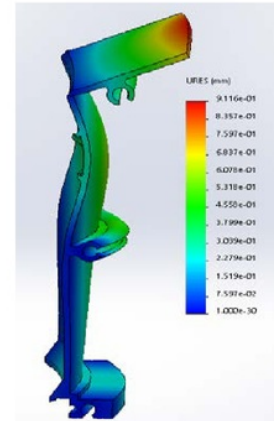
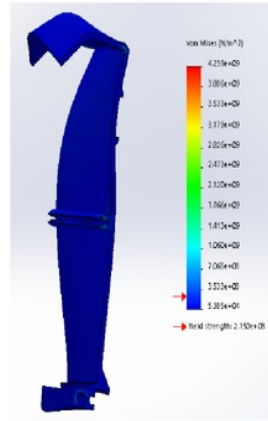


Figure 35. FEA simulation for the current design of AMC-985.

FEA simulation on large brige for curren design and the proposal has been presentet above. The force of 900N was applied to the front surface and the geometry was fixed approximately the same as COM1 prodcut is assmebled. Compering the simulation for the current design and the drop imapct test on AMC-985 the deflection is very similar +/- 9mm. As it can be seent the mechanical properties decreased. The stiffnes of a part decreased almost by 60%.

However intresting is the fact that the current design of SAL-501 is 48% less resitant to deflection than the proposed design for AMC-985 and both are parts of the fornt 'wall' of the COM1. For that reson the question shoud be asked how stiff and strong the product COM1 should be? Also, as the comnay has not received any feedback which indicated any damages or violence attacks on the product, so, is it necessary to reamin the magnitude of mechanical properties of the part?

Table 11. Summary of the analysis for COM1 current and proposed designs.

Current design			Changes in mass considering 'vee' grooves reduction		Changes in mass For proposed changes	
COM 1	length [mm]	mass [kg]	[kg]	Reduction [kg]	[kg]	Reduction in [kg]
2 x AMC_716	265	0.625	0.625	0	0.625	0
2 x AMC_716	389	0.929	0.928	-0.001	0.928	0
1 x AMC_985	235	0.473	0.474	0	0.392	-0.082
1 x SAL_501	231	0.314	0.314	0	0.314	0
1 x AMC 730	234	0.082	0.082	0	0.080	-0.002
	total	2.423	2.423	-0.001	2.339	-0.084
Mass reduction by						3.5%

To summarize the analysis of the COM1 letterbox the mass has been reduced by 3.5%, all data has been collected in the table 11.

In addition to the analysis, the information about the functions of all features in the COM1 product and the previous failure of introduced changes, has been gathered from the manufacturing manager but mainly from the operators of manufacturing processes used.

5 Cost

This part of the report concentrated on the cost of aluminium, extruded parts of COM1 product. The analysis of the cost is based on the information provided by the company that means the price of aluminium extrusion is £3.50 per kilogram, the rest of data is gathered in the Table 12. The SLB Company received the extrusion panels in a length of 4 metres.

Having no information about the waste production and the reason the assumption was made that the manufacturing processes and assembly was conducted without any mistakes. Also as the company present the pull system, so the parts are produced when ordered there is no target so the second assumption is that the cost was calculated only for A4 configuration.

Table 12. Provisional cos of Current design (assuming no mistake during the assembly process)

Part	AMC-716	AMC-716	AMC-985	SAL-501	AMC-730	Total
Length[mm] for A4	389	265	235	231	234	
Mass of one part[kg]	0.462	0.312	0.473	0.314	0.082	
Mass of 4m panel [kg]	4.852	4.852	8.053	5.467	1.394	
Number of parts from one panel	10	15	17	17	17	
Cost of # parts [£]	£16.20	£16.35	£28.22	£ 18.70	£ 4.93	£ 84.40
Cost for 4m panel [£]	£16.98	£16.98	£ 28.19	£ 19.13	£ 4.88	£ 86.16
Lost [£]	£ 0.78	£ 0.63	£ 0.03	£ 0.43	£ 0.05	£ 1.760
Waste	110mm 0.239kg	25mm 0.165 kg	5mm 0.010 kg	73mm 0.129kg	22 mm 0.008kg	0.551kg
Cost of scrap - £0.70 per kg	£ 0.17	£ 0.12	£0.07	0.09	£ 0.006	£0.456
Approx. final lost [£]	£0.61	£ 0.51	£0	£ 0.34	£ 0.044	£1.50

Table 12, consist the calculation for the cost of the current design of COM1 letterbox. The cost of one product is approximately £8.47. During the process the minimum waste production is 0.551 kg what results £1.50 lost for the company, considering the cost of a scrap £0.70 per kg. But, as it was mentioned earlier the price of a recycled aluminium changes every day what means the lost can fluctuate

To summarize the cost for aluminium extrusion to manufacture one COM1 letterbox is £8.47, the price did not consider the price of used pins and the stainless steel back wall and the security lock.

Table 13. Provisional cost of the proposed designs (assuming no mistake during the assembly process)

Part	AMC-716	AMC-716	AMC-985	SAL-501	AMC-730	Total for COM1
Length[mm]	389	265	235	231	234	
Mass[kg]	0.452	0.305	0.392	0.314	0.080	
4m long part [kg]	4.735	4.735	6.671	5.467	1.374	
Number of parts from one panel	10	15	17	17	17	
Cost of # parts [£]	£15.80	£16.05	£23.29	£ 18.70	£ 4.76	£ 78.60
Cost for 4m panel [£]	£16.57	£16.57	£ 23.35	£ 19.13	£ 4.81	£ 80.43
Lost [£]	£ 0.77	£ 0.52	£ 0.04	£ 0.43	£ 0.05	£ 1.83
Waste	110mm 0.211kg	25mm 0.155 kg	5mm 0.008 kg	73mm 0.129kg	22 mm 0.008kg	0.511kg
Cost of scrap - £0.70 per kg	£ 0.15	£ 0.11	£0.006	0.09	£ 0.006	£0.362
Approx.final lost [£]	£0.62	£ 0.41	£0.034	£ 0.34	£ 0.044	£1.45

The final mass of the parts needed to assembly COM1 from proposed parts is 2.3 kg, with the cost of £8.05. The capacity of recycled material would be 0.511 kg what means that the company would have lost £1.45, considering only one 4m panel for each extrusion.

From 4 metres long panel of AMC-716, a 3 completed COM1 letterbox for configuration A4 can be produced. Interesting conclusion is that the quantity of finished product depends on the planning strategy. That is to say, if the panel of AMC-716 is cut by the number of COM1 from two panels only 3 completed COM1 could be produced. But if the panels are cut by the number of needed body shell extrusion from two panels a 5 completed COM1 can be assembly. So, one conclusion suggested is the cutting process should be planned according to the order, to be as sufficient as possible.

Cost of recycled aluminium

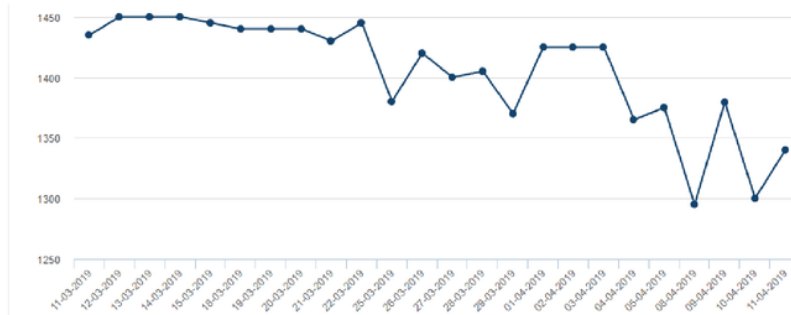


Figure 37 Aluminium Alloy historical price graph.

Companies engaged with buying scrap aluminium reports that the price not only aluminium but all metals changes on daily basis, as shown on the graph above produced by LME Company [26]. The changes create quite obvious correlation with the scrap price. It is difficult how the changes affect the prices for the extruded parts because the price include also the tolerance needed for the design. Bot only concentration on the scrap production it can gives an idea how important is or should be minimize the waste of the material as much as possible.

6 Manufacturing process analysis based on Lean-Sigma Methodology

Corrective, Improvement or Development are defined as types of analysis for problems occurred in the industry. Corrective type is implemented when the efficiency of the performance decreases. The tool recommended is, for instance, '8D' which stands for eight disciplines [27]. Another analysis defined is a progressive improvement. It has been applied when current performance does not meet a customer expectation or surely shows failure of product design or manufacturing processes used. An example of tool used is a 'Define Measure, Analyse Improve Control' (DMAIC). Finally the development type of project which consider redesign the process, by implementing lean transformation tools for instance, Prepare-Diagnose-Design-Plan-Implement-Refine and DMAIC is used as well.

Before the analysis it is important to explain what 'customer' in lean manufacturing means. McCarty [28] stated that *'The customer is the person, organization or department that receives*

an output of a process or activity within a process'. The output in a form of product or service can be delivered internally or externally.

For the further study the DMAIC methodology and DFA have been chosen.



Figure 38 DMAIC –Lean-Sigma Manufacturing

6.1 DMAIC

DMAIC - Design



Input: information gained from the company

Output: problem statement for the manufacturing processes used and assembly procedure

The main goal of this part of the project is to investigate the manufacturing processes used and assembly procedures applied for COM1 product. In order to demonstrate the achievement of stated objective the following part include;

- Measuring the time needed to finish the assembly of COM1;
- Quantifying the number of parts;
- Defying types of waste produced;
- Finally, proposed the solution for the potential errors.

The boundary condition for proposed continuous improvement were that the SLB Company did not want enlarge the production rate for this particular product as well as introducing automatization to the manufacturing process.

The data used in this investigation was collected during the visits in the Safety Letterbox Company.

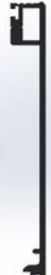
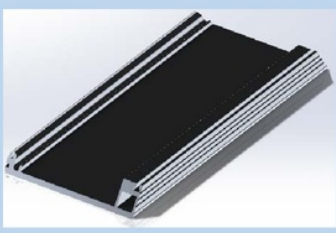
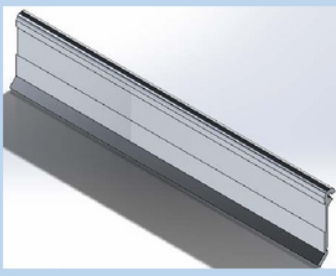
DMAIC - Measure

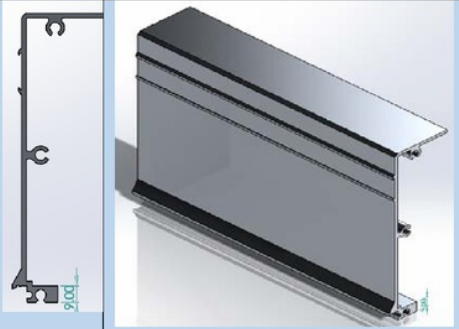
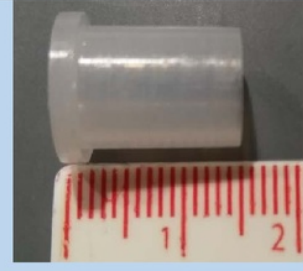


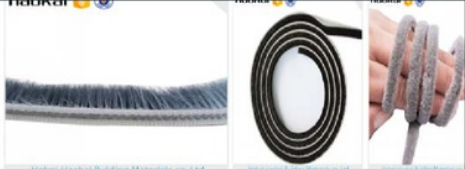
Input – information about the component and assembly, collected during the visit in the company

Output – Process Map, description of the assembly process in details

Table 14 Letterbox COM1 - CAD model of parts.

Part Name	PART Code	3D model	
		Front view	Orthographic view
<u>Body shell</u> Material of the part; Aluminium 6063 T6	AMC - 716		
<u>Small flap</u> • Material of the part; Aluminium 6063 T6 • The part can rotate approx. 90 • Free entrance (no lock) for an envelope • Max size of envelope – C4 (324mmx229mm). • Inventory – the part is cut and stored on painting work station. • Painted separately from the body shell then assembled.	AMC-730		
<u>Large Door</u> • Material of the part; Aluminium 6063 T6 • The part can rotate in 90 deg. In order to open and close the door. • Inventory – the part is cut and stored on painting work station. • Painted separately from the body shell then assembled.	SAL- 501		

<u>Large bride</u> - Material of the part; Aluminium 6063 T6 - The part is fixed. Assembled to the body shell by weld spot and pin on the bottom of the part. - The design consist of anti-fishing element. - Inventory – the part is cut and stored close to the welding work station	AMC-985	
- Stainless steel <u>cylinder pin</u> - Connect the body shell with a small flap. - It works as a hinge, so the part can rotate.	3 mm in diameter	
- Stainless steel <u>cylinder pin</u> - Connect the body shell with large bridge and large door. - It works as a hinge	6 mm in diameter	
<u>PTFE tubes</u> - Protects from galvanic corrosion. - It works as a part of the hinge and reduces the noise during rotation - It provides - low friction surface, very high resistance to chemicals and solvents. [32]		
<u>Lock – security (set)</u> 1 x Lock – 2 x Coded keys – 1 x Locking nut – 1 x Nut - Security aspect. - Keys are coded, specifically for use with each lock. It is possibility for replacement	SLB Security Lock Keys	

<u>O-Ring Cord</u> • Material – Nitrile Rubber • Provides a damping element • The rubber separates two materials aluminium large door and stainless steel pin what is treated as anti-corrosion treatment.	1 mm in diameter	
A waterproof door brush cabinet door dust seal		

'PROCES MAP'

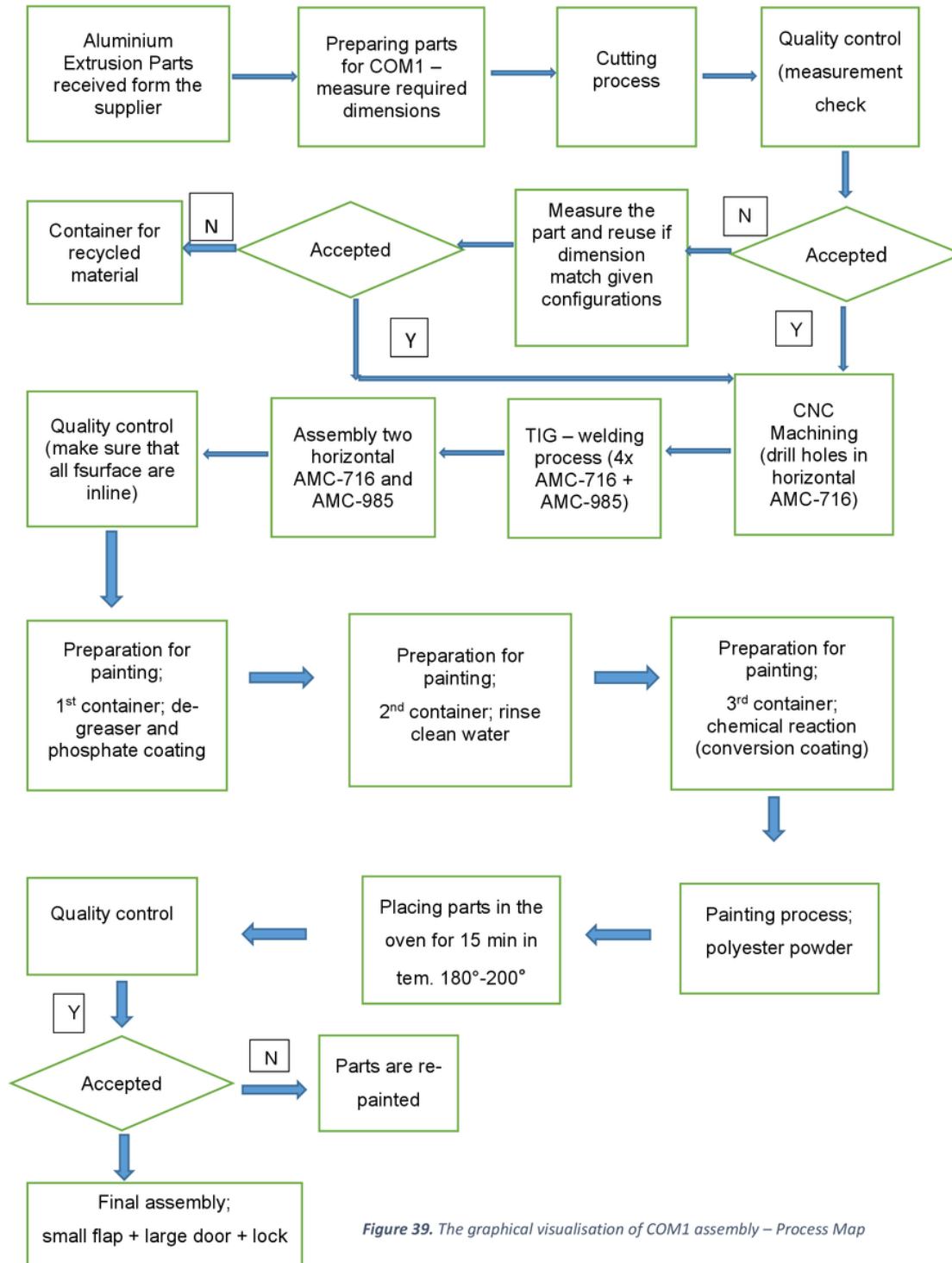


Figure 39. The graphical visualisation of COM1 assembly – Process Map

Firstly, the information about components used to build the COM1 product has been gathered in the Table 14. The next step was to design a Process Map depicted on the figure 40 in order to replicate all sequences and the workflow of the assembly. Having the base for further analysis a DFA methodology was used to detect all bottlenecks of the workflow.

The description of the Process Map.

1. The extruded panels are supplied by Hydro Extrusion Company Ltd. The panels are 4 metres long and they are handled by the one person, an operator of cutting machine.
2. The operator need to measure required length of the part. The panels for AMC-985, SAL-501 and AMC 730 are cut in the angle of 90°, and the body shell AMC-716 in an angle of 45°.

Then the sanding paper is used to polish sharp edges after cutting. To create a body shell structure 4x AMC-716 are cut, two in horizontal and two vertical dimensions. On that stage the operator need check the dimension of the cut pars, if the part is too short and cannot be used for different configuration then its rejected and placed in a scrap container.

3. The next step is a CNC machining process. 6mm and 3 mm holes are drilled on two vertical parts, AMC-716. In addition only that part of the whole assembly process is automated.
4. Manual bending of the large ridge, AMC-985 in order to create anti-fishing element.
5. Welding process where the operator create a body structure of the COM1 from four AMC-716 pieces previously cut and stainless steel back wall. The weld is placed inside the frame in the corners. Important is on that stage is a continuous quality control, that is to say the all edges and surfaces are perfectly aligned. Also the temperature during the TIG welding need to be changed from 145 to 185 depending on the thickness of the joint material.
6. The partially assembled letterbox need to cool down. It is important that the temperature is decreased naturally as that can affect the quality of the weld.
7. When the temperature of the body decreased to the room temperature it is prepared for painting process. Preparation include immersing all aluminium parts needed to complete assembly of COM1 three containers;
 - I. 1st container; de-greaser and phosphate;
 - II. 2nd container; rinse clean water;
 - III. 3rd container; chemical reaction for aluminium (conversion coating).

The operator of the process reported the content of the containers are exchanged every six months.

8. The appliance used for painting has been recently updated (for SamesKremlin-ejet2). The main difference between machines is that a new machine has embedded different levels for painting speed what potentially can improve the efficiency of the process.

The letterbox surface is coated with a polyester powder. One box contains 25 kg of powder and as the operator of the process reported 200 of COM1 can be completed from that amount.

9. Painted part is moved to the oven for 15 min in temperature from 180° to 200°. Next, the parts are removed from the oven and leaved cool down to the room temperature. At that stage important is a guilty check of the paint coverage. The parts can be repaint one more time, for that reason quality check before painting is crucial.

10. The number of the property is graved on small flap, AMC-730.

11. Final steps are the assembly of large door and small flap. When all aluminium extrusions are assembled the waterproof seal and the damping rubber is placed. Safety Letterbox provides security system with the keys and an instruction of how the lock can be replaced [30] in case of lost or stolen key.

DMAIC - Analyse



Inputs – data to analyse list of possible causes of increased production cost

Outputs – defining the root causes of inefficiencies

Aiming to suggest the modification the study is based on PFMEA and DFA methodology widely used in Six Sigma and Lean manufacturing.

Process Failure Mode Effect Analysis (PFMEA) is presented more in details in the Appendix1.

Table 15 RPN for Failure mode effect for the process.

Process	Failure	S	O	D	RPN
1.Cutting	Measurement mistake	9	8	4	288
2.Cutting	Internal failure (scrap, rework)	9	8	3	216
3.Painting	The process is not standardized	8	7	3	168
4.Cutting	Small, flying pieces of aluminium	6	5	5	150
5.Bending	Fracture/cracks anti-fishing element	7	7	3	147
6.Welding	Reworks	2	3	8	120
7.Cutting	Increased cost - corrosion	5	2	5	50
8.Cutting	External failure (repairs, guaranty)	6	3	2	36
9.Cutting	Anti-corrosion protection damaged	7	3	1	21
10.Cutting	Damaged correspondence	2	2	5	20

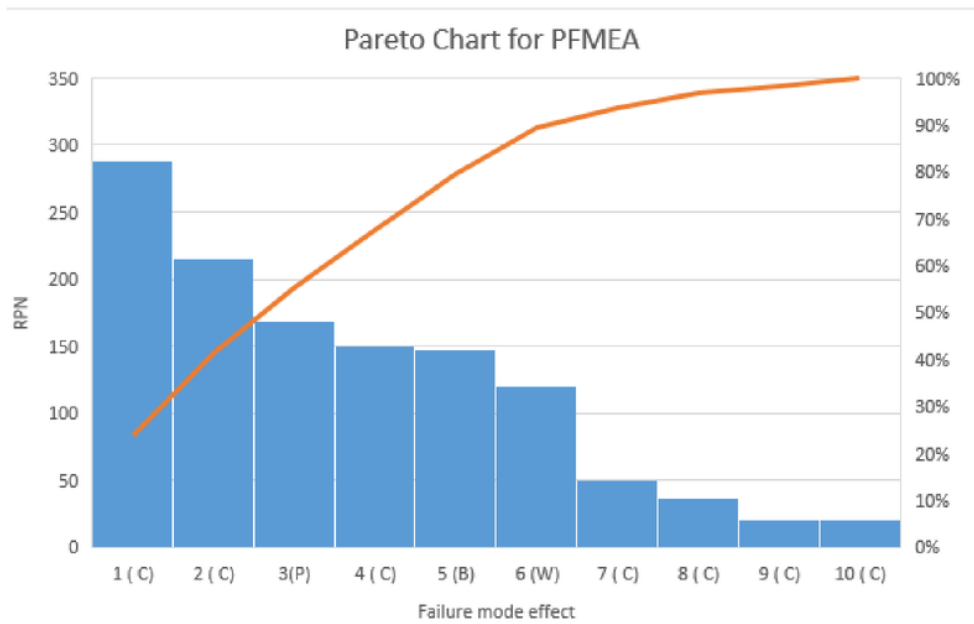


Figure 40 Pareto Chart for PFMEA. (C=cutting, P=painting, W=welding, B=bending)

The summary of PFMEA has been gathered in the Table 15. Listed critical failure modes associated with the manufacturing processes used by the company has been prioritized by the calculated Risk Priority Number (RPN) value. The Pareto Chart depicted on the Figure 40, reprints 80/20 Rule what in lean manufacturing means 80% of success can be achieved by focusing on 20% of problems causing the most defects, in different words with highest RPN.

Based on the Pareto Chart 20 % of failures addressed by PFMEA addressed are damage aluminium during bending process, poor standardization of manufacturing processes, the amount of recycled material, 'flying' small pieces of aluminium and the human errors such as measurement mistake where RPN value is the highest (RPN = 288). As it can be seen from the Table 15, the critical failures occurred during the cutting and painting processes.

According PFMEA analysis failures such as reworks, guaranty and anti-corrosion protection for material are less harmful for the process but still need to be considered as a future correction plan.

PFMEA is not perfect methodology for this reason it is used as a one of the many steps in Six Sigma analysis. One of disadvantages is that defying the priority of the failure base on RPN value can misdirect the improvement process. For instance the corrosion is a serious problem with high severity index, but because it is difficult to detect, what decreases the RPN and consequently the importance of the failure.

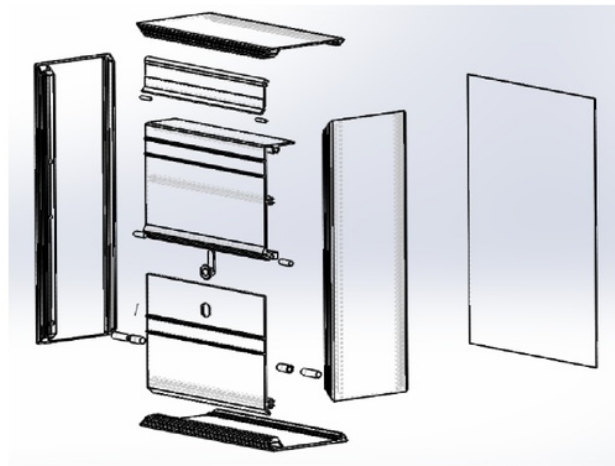


Figure 41 Current design for assembly COM1

Table 16. Design for Assembly (DFA). Design efficiency Index Calculations.

C1	C2	C3	C4	C5	C6
Component	Description	Number of times that the operation is consecutively executed	Assembly and insertion time by part (seconds)	Operation time (C3*C4)	Minimum number of parts estimated
1	Handle the extrusion part AMC-716	1	10 s	10	1
2	Measure the required length	4 (4 parts)	30 s	120	0
3	Cut AMC 716 in horizontal length, 45° angle	2	1 min (60s)	120	2
4	Cut AMC 716 in vertical length, 45° angle	2	1 min (60s)	120	2
5	Polishing sharp edges	8 (2e x4p)	10 s	80	0
6	CNC Machining – drill holes in horizontal AMC-716	2 (p)	2 min (120s)	240	0
7	Bending process AMC 985	1	1 min(60s)	60 (0)	0
8	Assemble AMC-716 + AMC-985	4 (6)	1 min (60s)	60	4(6)
9	Welding process	1	5 min (300s)	300	0
10	Cooling process (natural)	1	5 min (300s)	300	0
11	1 st container – de-greaser and phosphate	1	1 min (60s)	60(50)	0
12	2 nd container - rinse clean water	1	30 sec	30(20)	0
13	3 rd container - chemical reaction (conversion coating)	1	30 sec	30(20)	0
14	Dry the parts	1	15 min (900s)	900	0
15	Collecting parts for the COM1 (AMC-730 ; SAL-501)	1	1 min (60s)	60	2

16	Painting process	1	5 min (300) (180)	300 (180)	0
17	Oven	1	10min (900s)	900	0
18	Cooling	1	10 min (600s)	600	0
19	Graving the number on AMC- 730	1	3 min (180)	180	0
20	Handling, partially assembled COM 1	1	1 min (60s)	60	0
21	Assemble SAL- 501 (use pin 3mm to create a hinge)	1	1 min (60s)	60	2
22	Assemble AMC- 730 (use pins and PTEF tubes)	1	1 min (60s)	60	4
23	Assemble waterproof seal and the rubber	1	30 sec	30	1
24	Assemble security lock	1	1 min (60 s)	60	1
25	Assemble Name plate	1	30 sec	30	2
				TM	NP
				3240 (3030)	21 (23)
Design Efficiency <u>before</u> DFA				$\frac{t_m \times NP}{TM} = \frac{3 \times 21}{3240} \times 100\%$ $= 1.9\%$	
Design Efficiency <u>after</u> DFA				$\frac{t_m \times NP}{TM} = \frac{3 \times 23}{3030} \times 100\%$ $= 2.3\%$	

Design for assembly efficiency index is calculated through following formula;

$$\text{DFA index} = \frac{t_m \times NP}{TM} \times 100\%$$

Equation 1 Design for Assembly Index or design efficiency. [18]

Where

EP = Design Efficiency

NP = Number of parts

TM = total Assembly time in seconds

t_m = minimum assembly time per part

All measurements were recorded on the visit in the company. Unfortunately the data was collected on one working so gathered information are unilateral as weren't compared with operator from other working shifts. Also assumption were made that investigated manual assembly process was operated without any mistakes and delays.

Table 16, consist all information necessary to conduct DFA and calculate the design efficiency index form Equation 1. Despite the fact that the design efficiency index has increased by 0.4% and the time required decreased by 210 seconds the number of parts increased by two stainless steel pins. Considering the design the company need to justify which aspect will be more beneficial for the customer or for the company. That is too say increase the number of the part by two more pins and the same time reduce overall mass of the part by 13%.

Ohno's Seven Wastes

1. Overproduction

As it was mentioned earlier in the report the SLB implemented pull system, so it can be said that the overproduction is not the company concern. The letterbox COM1 is produced only when the order is placed Also the company order material based on the current order and available space for the inventory.

2. Waste of waiting

During the painting process the operator need to wait for the parts to be dry after soaking in the three containers. As it was recorded during the one of the visit in the company, different operators have a different system of working that is to say one used an automated system, the second operator approach the process manually. As the process is not standardized, the probability of creating inefficient process increases.

3. Waste of necessary motion.

Based on the observation on one of the visit in the company it can be said that SLB Company introduce some tools from lean manufacturing in order to reduce the waste of necessary movement. The shadow boards have been mounted on every work station.

It need to be mentioned that the company, is limited by the small space of the workshop where the COM1 is manufactured, but despite this disadvantage designed direction of the assembly is as sufficient as possible.

4. The waste of transport.

Knowing that the SLB Company outsourced the extrusion parts from Hydro Ltd. The supplier is located approximately 45 miles from SLB Company and it is the nearest, on the map, company producing the extrusion in Wales.

5. The waste of over-processing

After analysis of every part used for assembly COM1 it is know the bending process applied in order to create anti-fishing element can be removed. The change included re-designing the AMC-985.

6. The waste of inventory

To manage inventory of the painting powder the company has introduces a KANBAN system, called 'two bin Kanban System'. The main goal of the system is to have enough inventory to continually produce outputs. Many companies choose only that system as small volume is easier and quicker to order, and can receive quickly.

In addition, the tool is used simultaneously with pull system. The main ides is that the powder box is supplied by rotating containers [2]. Only two boxes for each standard colour are kept in the stock. So when first box is emptied, the operator switch to the second box, while at the same time the order is placed to replenish the required stock capacity.

The main advantage of the system are optimization inventory volumes and waste reduction, what consequently leads to total cost reduction.

The company keeps inventory for Standard RAL Colours Finish. [31] For non-standard colour the customer need to make an additional payment as the company need to order it when the order is placed.

7. Waste of defects

Previous calculations of the cost produced waste was mainly based on the assumptions. The process of measuring the capacity of recycled aluminium was limited as the company has not

provided any information about how much material is wasted. In addition to the subject, the number of produced defects and reason were not measured.

All detected wastes are non-value adding activities and by definition should be eliminated in order to reduce the cost of a production. However the waste of 'transport' is difficult to replace so it can be considered as a necessary non-value adding activities as the SLB clearly does not want to change manufacturing processes used for instance to automate the process like Renz Group.

DMAIC - Improve



Inputs; the result from PFMA, DFA and FEA solutions

Outputs; robust and validated solution, recommendations for improvement.

Based on conducting analysis of COM1 product and assembly procedures used they are several options proposed for consideration for Safety Letterbox Company.

The project has shown that the current design and assembly procedures used affect the total cost of production COM1 product. The recommendations opted for the cost reduction and continues improvement are;

- Create definition of mechanical properties required, for instance measure the weight of the installation and how that affect the structure of investigated product. As more realistic and detailed gathered data is, more reliable and constructive 'repair' plan could be.
- Second, very important reminded strategy is to reduce the '7 wastes' described. One of the solution is to measure the amount of waste production on daily basis, including information such as the name of the operator, the nature of error, the time, what strategies were used to correct the problem, by introducing non-conformance report. By representing regular updating this information in a graphical form the company would build an awareness of the problem as well as encourage everyone in the company for improvement, for instance by introducing a Statistical Process Control. By facilitating an easy access to the information, the processes could be observed and measured regularly.
- Standardization of the work procedures is another aspect which need to be reviewed. For instance, to investigate the current procedures used by every operator during the assembly.

Based on gathered information, combine their ideas and 'design' the most efficient procedures for manufacturing processes and assembly, but reaming a high quality product.

- Finally, in cases for installation near the coast in the area with corrosive air a 'filiform corrosion' can arise especially on coated aluminium parts. If this is a problem, and the place of installation cannot be changed, the company could provide an information for the customer about procedures for cleaning and care of the surface as well as the scratches could prevent the corrosion.

DMAIC – Control



The Final step of DMAIC, Control will not be included in this project as detailed recommendations require more time and financial investment and that is not a part of a project.

7 Conclusion

The project considered several objectives. The main purpose was to reduce the weight of the investigated product COM1, manufactured by Safety Letterbox Company and simultaneously reduce the cost of a production. That aspect of analysis included;

- Re-designing current models of every aluminium extrusion based on technical drawings provided by the SLB Company,
- Propose changes to geometry with explanation how they will affect the mechanical properties such as strength and stiffness
- Also, how the proposed changes will potentially affect the total cost of aluminium extrusion parts supplied by Hydro Extrusion Company.

Before summary of the results it is important to mention that in order to investigate the stated aims some assumptions had to be made;

1. The visit in the organization was arranged only on one from two working shift, so the gathered information represent small element of that how the process is conducted o daily basis. That limited the source of information to design as much realistic picture as possible.
2. The company wants to remain the production rate of the product.

3. Although the business partner, Renz Group has built a completely automated process to manufacture mail and parcel boxes, SLB wants to continue adapted manual processes such as cutting, welding and panting. For this reason non advanced manufacturing methods were advised.
4. The calculation of the cost for extrusion component were based on information given by Manufacturing Manager of SLB. That is to say, approximate price £3.50 per kilogram of alumina alloy.
5. The calculation of the capacity and the cost of recycled material was based on the 'perfectly' conducted process without errors.

The first part of the project concentrated on parts used to assembly COM1 that is to say; AMC-716, AMC-730, SAL-501 and AMC-985. The technical drawings of current aluminium extrusions were provided by Keith Jones. Before any research important was interpretation the geometry, defining the function of all features as well as understanding the manufacturing processes applied.

The first observation was the large bridge AMC 985 part was the heaviest part as its geometry consist of two reinforcement feature. After consultations with Manufacturing Manager and one of the operators the real function of the reinforcement was defined. That is to say, the main reason of applying reinforcement to the geometry was not to improve the mechanical properties of COM1. The function one stiffener was to prevent the part from fracture during bending process, and the second's main function was to create the surface for the weld to join the AMC-985 with body shell frame.

Another interesting observation was the comparison the mechanical properties of the large door and proposed design for the large bridge. That is to say the FEA simulation shown that adjustment the geometry of AMC 985 has reduced the mass of the part by 13% as well as reduced resistant to fracture and deflection. But the part remain stiffer by approximately 48 % than the current design for SAL-501, and as it was mentioned before these two parts creates the front surface for the COM1 product and are exposed to the same external forces. So at this point the conclusion could be made towards SLB Company, how strong and stiff their product should be?

Also the mass of the small flap has been reduces by 1.5% without scarifying mechanical properties of the part. Finally, the provisional mass of COM1 product, considering only aluminium extrusion parts, was reduces by 3.5%.

Based on assumed price for the aluminium extrusion, £3.50 per kilogram the company potentially can save 5% as calculated difference in price between the current and proposed design for only one COM1 was £ 0.45. Another calculation concentrated the cost of recycle

material. And as it was expected the company lost was estimate approximately £1.5 per one COM1 product. However this approximation is no a reliable quantity for constructive conclusion. The reason is, as explained earlier, the price of scrap fluctuate on a daily basis, also the calculation did not consider human or machine errors. But following the lean manufacturing hypothesis that the company should strive to 'zero waste production' in order to reduce the cost.

The results extracted from applied Lean-Sigma methodology are concentrated on 'Ohno's seven wastes' produced during the process. Calculated efficacy indexed for current and proposed design for assembly shown improvement only by 0.4%. So it can be said that DFA analysis shown that the main problem is not the velocity between the moment of placing the order and delivery of product to the customer. The main hinder in continuous improvement and cost reduction is the uncontrolled production of recycled material and absence of work standardization. The PFMEA shown that these two aspect are potentially a main root cause's total cost growth. In addition, poor standardization of the process and uncontrolled waste production have 'scored' the highest RPN number in PFMEA.

From this it can be concluded that SLB Company should consider every aspect of the production in order to reduce the cost of manufacturing the COM1 product. For instance by implementing a preventive strategy such as monitoring and control the process. The suggestion could be introducing a separate container for recycled material to measure how much material is wasted because the human error and how much for the reason that the geometry does not fit any given configuration and cannot be reused.

Another solution for the problem could be implementing a non-conformance reports which by definition, must include all conducted mistakes, the reason, what can be done to prevent the form happening again.

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APPENDYX

Potential Effect(s) of Failure	Severity	Potential Cause(s)/ Mechanism(s) of Failure	Occurrence	Current Process Controls	Detection	RPN	
damaged anti-corrosion protection	6	The body shell is cut in angle of 45° in order to assemble 4 parts to create a body shell of the box. Also the stainless steel back wall is in direct contact with aluminium body shell what causes corrosion of the aluminium.	5	none	5	150	Research on advanced method/materials which could eliminate/reduce the corrosion. Separate the stainless steel back wall from aluminium body shell by any suitable sealing. Provide an information leaflet for the customers with instruction on how to prevent or 'slow down' corrosion.
additional cost for the company	5	the letterbox need to be serviced or replaced (the guarantee)	2	customer's complains	5	50	Calculate the potential loss of money. Record data regularly about what section of the COM 1 is corroded, consequences, Where the box was mounted.
damage the content of the letter box (the owner correspondence)	2	Most of the letterboxes are mounted outdoor, (offshore environment, rainy weather) 'benefit' the corrosion what consequently can destroy the structure of the letterbox.	2	none	5	20	Measure the level of the problem and the cause of the failure
internal failure (scrap, rework)	9	The measurement mistake, lack of planning ahead	8	none	3	216	Introducing pre-measuring process before cutting, define the dimension and plan ahead Introducing control and monitoring of every error, including details about the nature of the error. For instance was it a human error, machine or others.
external failure (including warranty, repairs)	6	Poor, final quality control.	3	final, visual, quality control	2	36	Introduce a non-conformity report. Visual board with graphs Interpretation of current situation, showing improvement or reduction in quality/waste production
additional cost in a short and long period of time	9	mistake during a measuring process , lack of planning ahead, poor or none quality control	8	none	4	288	introduce a non-conformity report (to measure how much material is waste by mistake and how much material is wasted as a left-over material)

cracks on the extruded aluminium surface	6	Aluminium is extruded along longitudinal (grain) direction, and the part is bended, also in the grain direction.	4	visual quality control	2	48	re-design the part considering extrusion process procedure and tolerances
additional weight	7	One reinforcement feature was added to prevent fracture while bending in order to create any-fishing element. Potentially over-designed part AMC-985	7	None	3	147	
poor quality of weld	2	operator with lack of experience	1	visual quality check	6	12	The welding has a high level of quality. One recommendation which could be considered is to make sure the weld surfaces are clean, to improve the joint quality.
	3	the material surface has not been cleaned before the welding, especially aluminium	5	None	8	120	
rework	2	too high/low temperature for designed thickness, weld voltage, inert gas flow rate, weld wire feed flow	3	one seal, keep away from water	8	48	
weld voids, rework, product safety hazard	4	current settings incorrect due to inadequate operator instructions	1		4	16	
thin beads, weld voids, rework, product safety hazard	1	voltage settings incorrect due to inadequate operator instructions	1	Operator instructions, visual quality control	8	8	
overall time of the manufacturing process increases	8	the speed of the machine is not standardized	7	none	3	168	Standardized the procedure and the setup for the machine. Visible instruction to be placed where the painting machine is placed.
the speed of the machine is not standardized	8	without standards different operators produce different quality for the same product in different time	7	none	3	168	
cleaning and coating (3x containers explained earlier on) process not standardized	4	Different operators has different way of approaching the process, automation vs hand operating.	7	none	2	56	Standardize the procedure of the process.
the waste of necessary motion (production time increases)	7	poor surface quality control,	4	none	9	252	Make sure that the quality control is on high standard. Introduce a non-conformity report. Design graphical interpretation of the measurements. For

poor surface quality	7	too much paint on the surface, or the first layer of paint was not cleaned properly	2		2	28	instance, how many parts per moth have been re-painted, put in the recycle bin and approximation of the cost and time lost.
part placed in the recycle bin	7	too much paint on the COM1 surface	2	quality control	1	14	
injuries to employees	7	only operator of the cutting machine wears the PPI (protection glasses) but other workers can be injured as small, flying pieces are spread over the workshop	3	none	1	21	Implement a protection guard (wall). Redesign the machine so that the small pieces of aluminium will be collected in one container during the process
The waste of unnecessary motion, cleaning	6	The employee need to clean the station more often and longer	7	none	1	42	Investigation and measure the current process,

