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Executive Summary

The purpose of this report is to provide TDS Appliances Ltd. with guidance on redesigning the Cookwork's Deep Far Fryer through utilizing Design for Manufacture (DfM) and Design for Assembly (DfA) methodologies. This aim towards analyzing the subassembly of the fryer using Durham method from the manufacturing and assembly perspective. The DfA and DfM matrices with different color codes are created as a group work for application of the tools on the lid subassembly of the fryer. Also, this report suggests and discusses the redesign of the product for making it more suitable for efficient manufacturing, reducing the material usage and simplifying assembly procedure, boosting the production rate.

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Introduction

This report focuses on redesign of the Cookwork's Deep Fat Fryer considering manufacturing and assembly aspects of the product, based on the previous analysis done using DfE to improve overall sustainability of the Fryer. The analysis, suggestions and redesign proposed in this report is directed towards host manufacturing company TDS Appliances Ltd, in order to help improving the existing fryer product. For this study, Durham method is used as DfMA tool. Designing for assembly and manufacturing enables the identification, quantification and elimination of waste within the manufacturing and assembly process. This helps to implement cost-effective manufacturing and minimize the complexity of assembly, speeding up and simplifying the production process. This in turn leads towards sustainable feature and benefit of the company to grow while maintaining the ethics. A subassembly was chosen from the product to implement this method and while working in group, gathering the suggestions and generating the suitable design based on improvements notes gathered during the analysis procedure.

Summary of DfE Analysis

The first assignment was focused on utilizing different DfE tools and redesigning the product considering the environmental impact while making it more sustainable. The fryer was disassembled with the help of general tools like screwdriver and plier. The disassembly of the product was easy and can be done about in 30 min with no extra hand. Some of the parts like lid and basket were separated from main body easily. Removing heating bowl and heating unit was complex part. Although lid had many assemblies, it was simple process. After recording and analyzing every component of fryer, bill of material was generated and view of the product in exploded manner was captured.

Lifecycle and Functional analysis were done for better understanding of the product. It helped to pinpoint the use of the components in the product and how it affects environment over its lifecycle time in brief. Then the DfE analysis was done using different tools like MET matrix, Macdonald-Smith and T short, Luttropp's 10 golden rules as well as DfE matrix. MET matrix provided evaluation based on 3 environmental categories Material, Energy and Toxic emissions briefly to reduce impact over the life of the fryer. Macdonald-Smith and T short provided more in depth and quantitative analysis and clear areas for improvement. Luttropp's 10 golden rules provided suggestions for improvement by discussing the flaws in fryer. Finally additional method used, DfE matrix gave factors of product which are affecting the environment the most in calibrated numerical value.

From the findings of the application of all of the tools, improvements to the design were incorporated and redesign was suggested to the TDS Appliances Ltd. to make fryer more environment friendly. The redesign was mainly focused on reducing the packaging and making it more suitable for recycling, reducing the number of the parts involved making the lid, replacing toxic materials, and separating the heating element for ease of maintenance, repair and disposal. This DfE approach helped product to move to 'cradle-to-cradle' from 'cradle-to-grave' with the new redesign, making it more sustainable and minimizing the negative impact on environment.

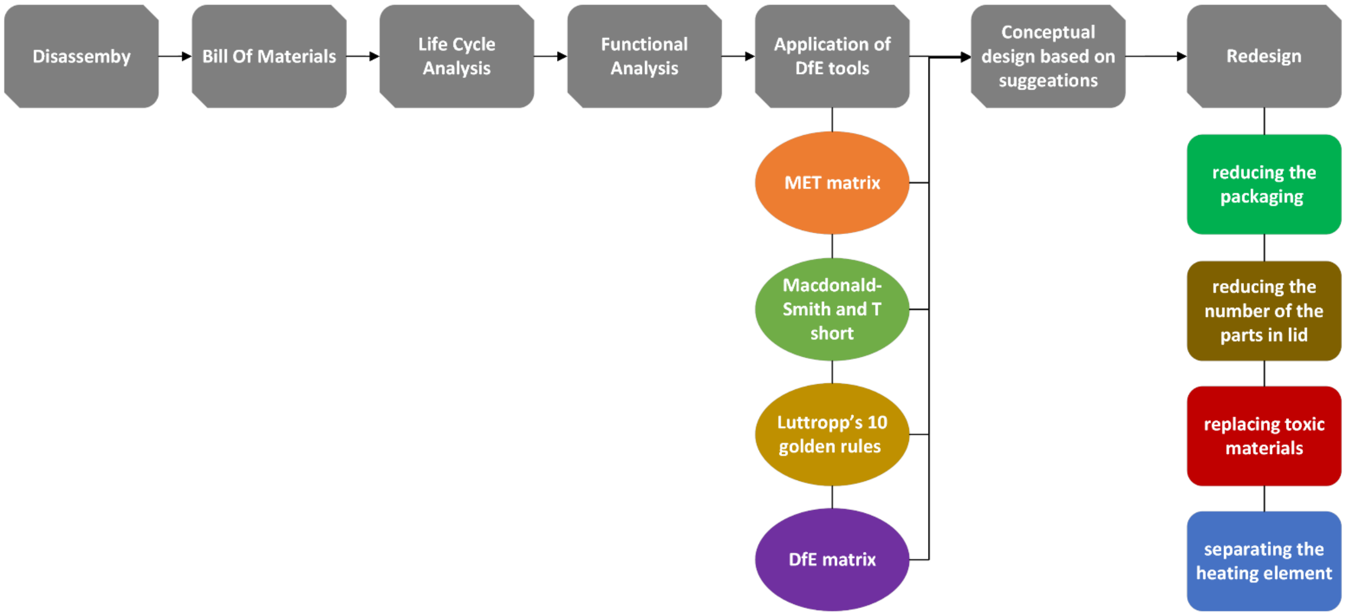

Figure 1: Block Diagram of Summary Outline of DfE Assignment

Overview of DfA and DfM Tools

Over 70% of the final features and cost of the product is determined in design phase. As it has such influence on ultimate result it is crucial to minimize it in design stage only. Hence, DfMA tools are essential to analyze this in depth and improve the design for ease of manufacture and assembly. The Design for Assembly (DfA) tool mainly focuses on reducing difficulty to assemble the product within short period and low cost. This helps to notice the drawbacks and change design to improve assembly process and serviceability. The Design for Manufacturing (DfM) tool target the effective manufacturing of individual components to reduce the steps, material and energy required, ultimately saving the cost. This motivates to settle on simple to manufacture and effective design, making product cost-effective.

There are several tools for this purpose like Knight method, Boothroyd, Dewhurst and Durham. Benefits of using these different tools is that they expose different lacking areas of product from different aspects, and it becomes easy to improve them. The limitation is that tool do not provide exact solution for improvement, it is up to designer to find better suitable improvements. These tools need additional cost analysis, so it is necessary to keep in account for it.

The first method discussed is 'Boothroyd Method'[2] which is represented in Fig 2. The concept of the product design is subjected to DfA, then improved on suggestions based on early DfM cost analysis. Depending on these estimates, basic concept design is modeled, on which the DfM is applied, and detailed design is refined for prototyping. The changes in design concept can be made in each step as we move further down the process.

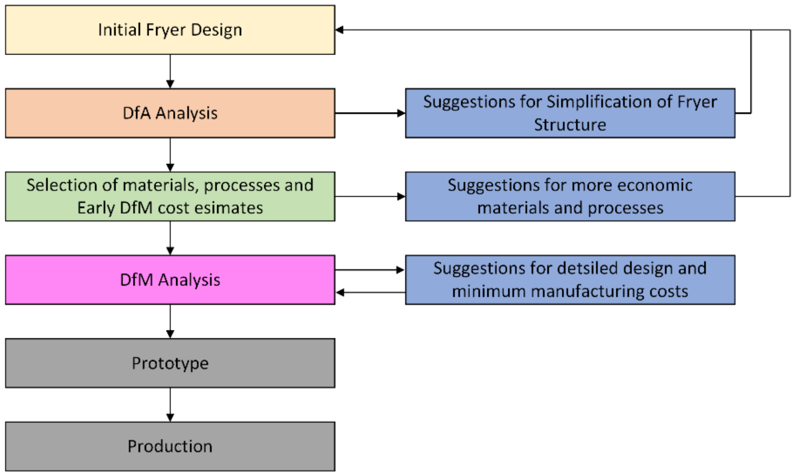

Figure 2: Block Diagram of Boothroyd Method applied to Fryer

Another method is the 'Knight Method' which can be seen in Fig . The underlying philosophy is that conceptual design modeled earlier, which reduces costs as mistakes are identified during a phase where they are easily fixed. A cost analysis tool is used to evaluate the assembly or manufacturing during early stages of design, to help reduce costly changes further down the design process.

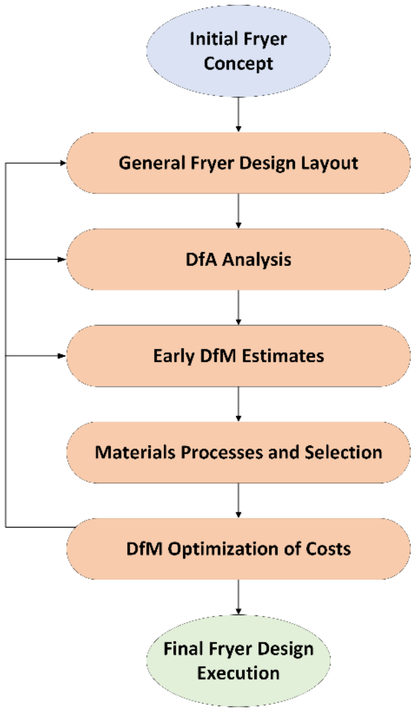

Figure 3: Block Diagram of Knight method applied to Fryer

For purpose of this report, team-based Durham method[3] is used. This is very structured method to apply the different opinions and suggestions of team members to develop the DfA and DfM matrices with best optimum results. To summarize the methods used for this report, a flow chart showing sequence of steps is presented below-

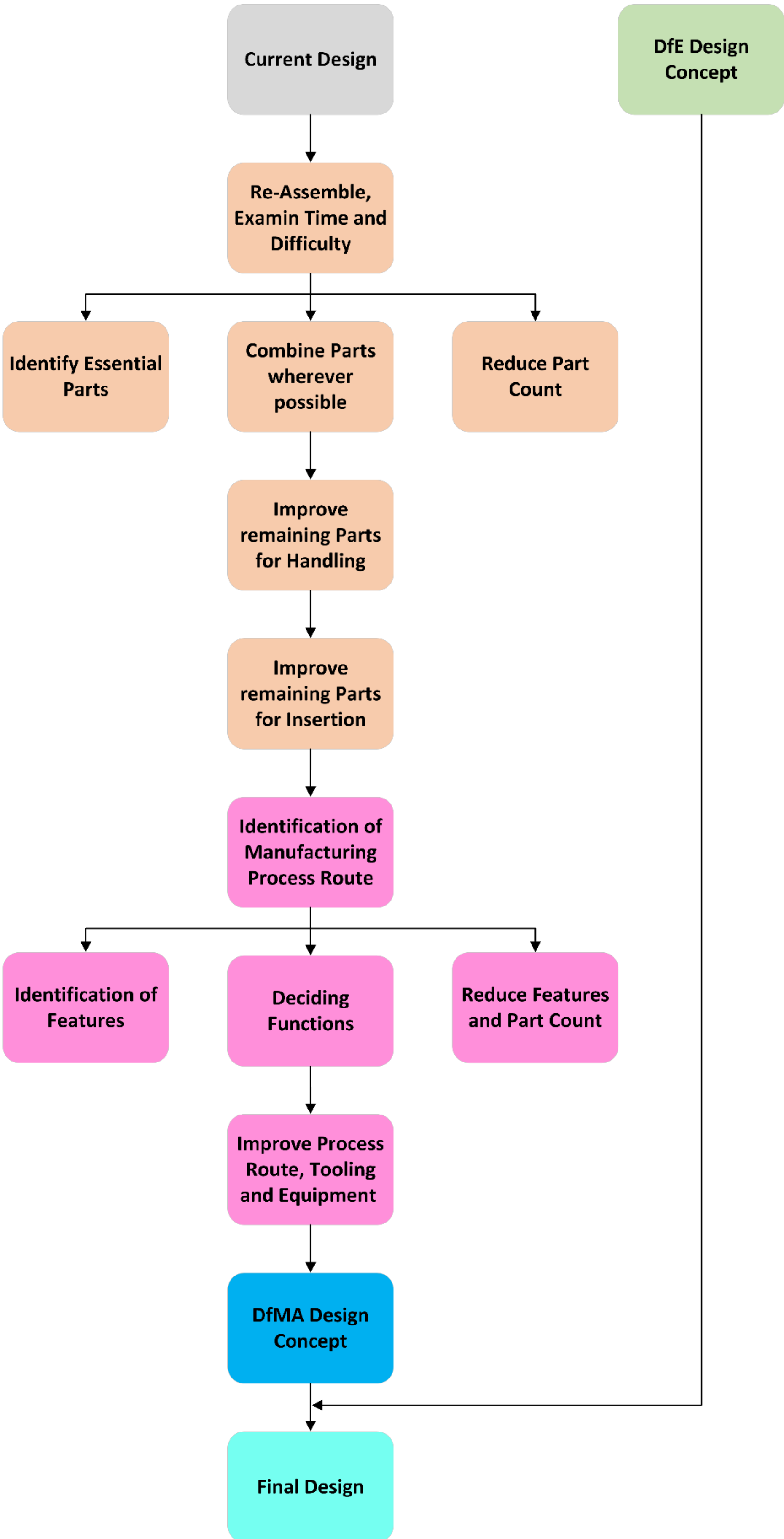

Figure 4: Block Diagram of Summary Outline of the Process followed

Application of DfMA Tools

The tools have been applied to the self-opening lid subassembly of the deep fat fryer. This assembly was selected because it consists of most variety of parts with different materials is used and it is quite complex for its simple function. It consists of parts – Lid, Lid interior faceplate, screws, glass, filter, filter cover, latch, hinge pin, spring and hinge cover. Before actually working on the product, the aim and features of the tools were discussed and understood in the group. First DfA, then DfM was used for the analysis and matrices were built as group effort.

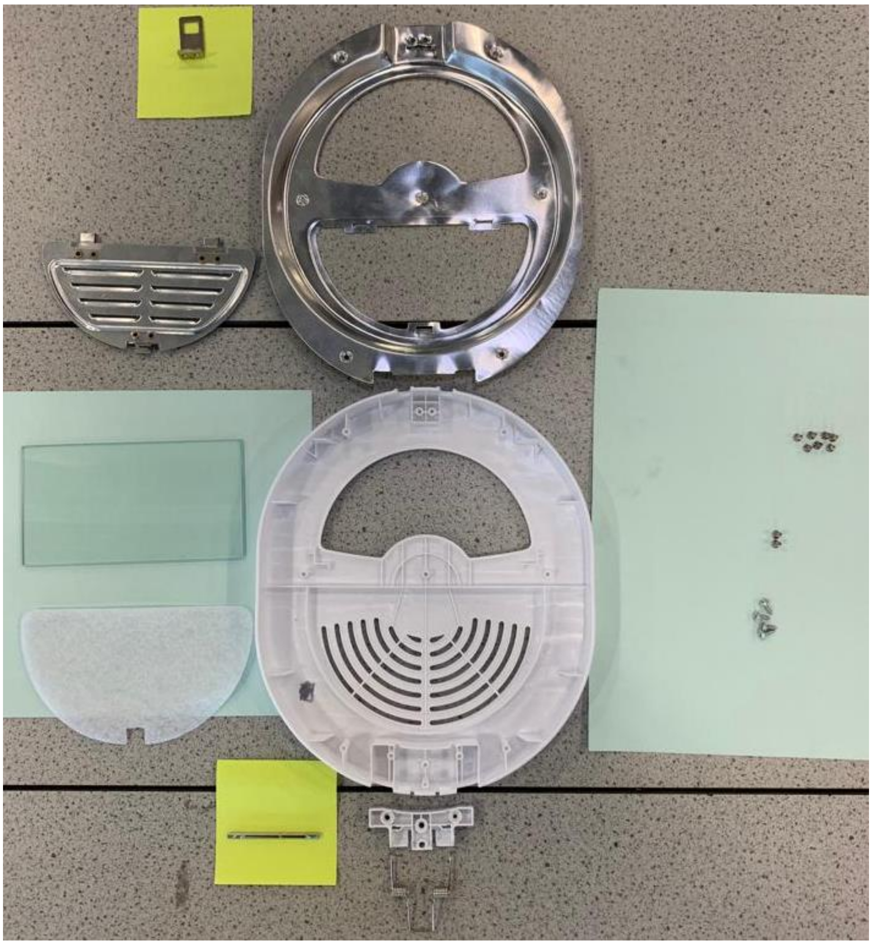

Figure 5: Exploded View of Subassembly of Lid

Aims of DfA and DfM Analysis

The purpose of this analysis is to understand the current manufacturing and assembly procedure utilized to make the product and their function, importance in the working of the fryer. Using the DfA and DfM, essential parts to be refined and improved in new design for ease of production and supplementary parts to be eliminated or to be fused with the essential parts, wherever possible. The main goal is to simplify the manufacturing and assembly process by reducing the number of different materials used and minizine the complexity of assemble these parts together via different routes to provide optimum design to TDS Appliances Ltd.

DfA Matrix

First, the selected subassembly was actually assembled according to the sequence in measured time window. It was also recorded using camera for future reference and making notes. After carefully analyzing the sequence of the process, tools used, time taken and difficulties occurred, observations were made and group discussed on the whole process. Then as a group, we built the matrix on big sheet using coloured post-it notes while sharing different opinions and suggestions.

For making the matrix, it was broken down in four phases. First phase includes gathering the information about the assembly process. The assembly sequence was written down on pink post-it notes in order of assembly. Then related parts used for assembly were written below on yellow post-it notes. The main plastic lid is considered as base here and other parts like hinge, glass, filter and faceplate was attached to it in order. Observations while following this process were noted on orange post-it notes. In second phase, changes were implemented to reduce the parts in number. Changes were mentioned on post-it notes and revised parts with assembly process is mentioned below.

The third phase is focused on improving the handling of the parts while assembling together. The parts which were difficult to handle were marked with 'Green H' and aimed to remove, if possible. Process was significantly changed depending on the design altered. Finally, fourth phase was applied to enhance the insertion ability of parts. Snap fits and other aligning mechanisms were used to make insertion of parts easy and firm, instead of screws. The final revised assembly process is written on pink post-it notes.

The initial and final assembly sequence was compared and significant change was observed in number of assembly steps required. But the improvements here should not be finalized without considering DfM matrix. Also, DfA matrix changes should correspond to changes in DfM matrix. Although, the photo of matrix developed in group is below, some minor changes are incorporated in individually created matrix (Fig 7).

Figure 6: Picture of DfA matrix done in Lab

Colour Coding:

Key	Assembly / Order	Parts	Changes in design	Essential Feature	Non-essential Feature
Colour Code					

Key	Notes / Observation	Easy Handing	Difficult Handing	Easy Insertion	Difficult Insertion
Colour Code		H	H	I	I

Phase												
Phase 1: Collecting Information	Assembly sequence		Fit hinge spring inside hinge cover	Slide hinge pin into hinge assembly	Fit hinge assembly into lid	Screw hinge assembly to lid with screws	Place the glass in lid	Align latch with lid screw holes	Align lid cover with lid assembly	Screw lid cover and latch to lid	Insert filter	Attach filter cover
	Parts added	Hinge spring H I	Hinge cover H I	Hinge pin H I	Lid H I	Countersunk x-head screws H I	Glass H I	Latch H I	Lid cover H I	Countersunk x-head screws H I	Filter H I	Filter cover H I
	Notes on Processes and Parts		3 assembly methods only 1 correct	Difficult to insert pin into assembly		Takes a lot of time to assemble	Rigid order of assembly	Rigid order of assembly	Rigid order of assembly	Takes a lot of time to assemble	Replaceable	Not securely attached
Phase 2: Part Count Reduction	Change to Reduce Part Count	Moulded snap-fit hinge	Moulded snap-fit hinge	Moulded snap-fit hinge	Moulded snap-fit hinge	Removed	Solid lid without viewing window	Snap fit lock	Holes for snap fit to lid	Replaced with snap-fit fasteners	Vents	No cover
	Essential Parts				Lid				Lid cover		Filter	Filter cover
	Revised Assembly Process								Snap fit lid cover to lid		Place the filter in lid	Attach filter cover
Phase 3: Improve Handling	Changes to Improve Part Handling	Moulded snap-fit hinge	Moulded snap-fit hinge	Moulded snap-fit hinge		Removed	Removed	Snap fit lock		Replaced with snap-fit fasteners		
	Easier Parts to Handle				Lid				Lid cover		Filter	Filter cover
	Revised Assembly Process								Snap fit lid cover to lid		Place the filter in lid	Attach filter cover
Phase 4: Improve Insertion	Changes to Improve Part Insertion	Moulded snap-fit hinge	Moulded snap-fit hinge	Moulded snap-fit hinge		Removed		Snap fit lock	Holes for snap fit to lid	Replaced with snap-fit fasteners		
	Easier Parts to Insert				Lid		Glass				Filter	Filter cover
	Revised Assembly Process								Snap fit lid cover to lid		Place the filter in lid	Attach filter cover

Figure 7: DfA Matrix

DfM Matrix

After DfA, DfM matrix was built as a group effort. For this, as a group we discussed and decided the manufacturing route considering different parts made from different materials. This activity is divided into 6 phases for simplicity.

First phase consists of collecting information about parts. Appropriate manufacturing process route used was written on top with pink post-it notes. All the features were listed produced by the manufacturing method blow them on yellow post-it notes and their function was listed below them on green post-it notes. Essential features which are must in final product were marked with ‘Red dot’ and secondary or non-essential features were marked with ‘Green dot’, these are to be modified or eliminated in further stage.

Second phase is feature reduction. Here without inferring the function and quality of the final product, some features were removed and design changes made accordingly. Snap fit design is suggested to eliminate screws and holes required for them. In phase three, process route is reduced while keeping the essential features. The necessary processes are marked with ‘Red P’ and non-essential were marked with ‘Green P’. Design is revised to avoid the process marked with ‘Green P’. Then manufacturing process is refined for material efficiency in phase 4. Parts with easy to manufacture materials are marked with ‘Red M’ and ‘Green M’ for eliminated or changed material. With snap fit features, screws are avoided, saving the material and making it cost effective. Incorporating glass just for visibility inside the fryer, only when not in use, is not much efficient. So, glass and its feature is reduced, saving the material and making it cost effective.

Phase five is focused on reducing the tool complexity, making manufacturing quick and cheap. Easy tooling equipment were marked with ‘Red T’ and wherever there is room for improvement with ‘Green T’. Some alternative tooling methods were suggested, but design is not changed much for this. In last phase, design is revised to use less machines to manufacture and handle the parts and final process is written with revised features. The first and final process routs were compared, observing the reduced process with less complexity. Although, the photo of matrix developed in group is below, some minor changes are incorporated in individually created matrix (Fig 9).

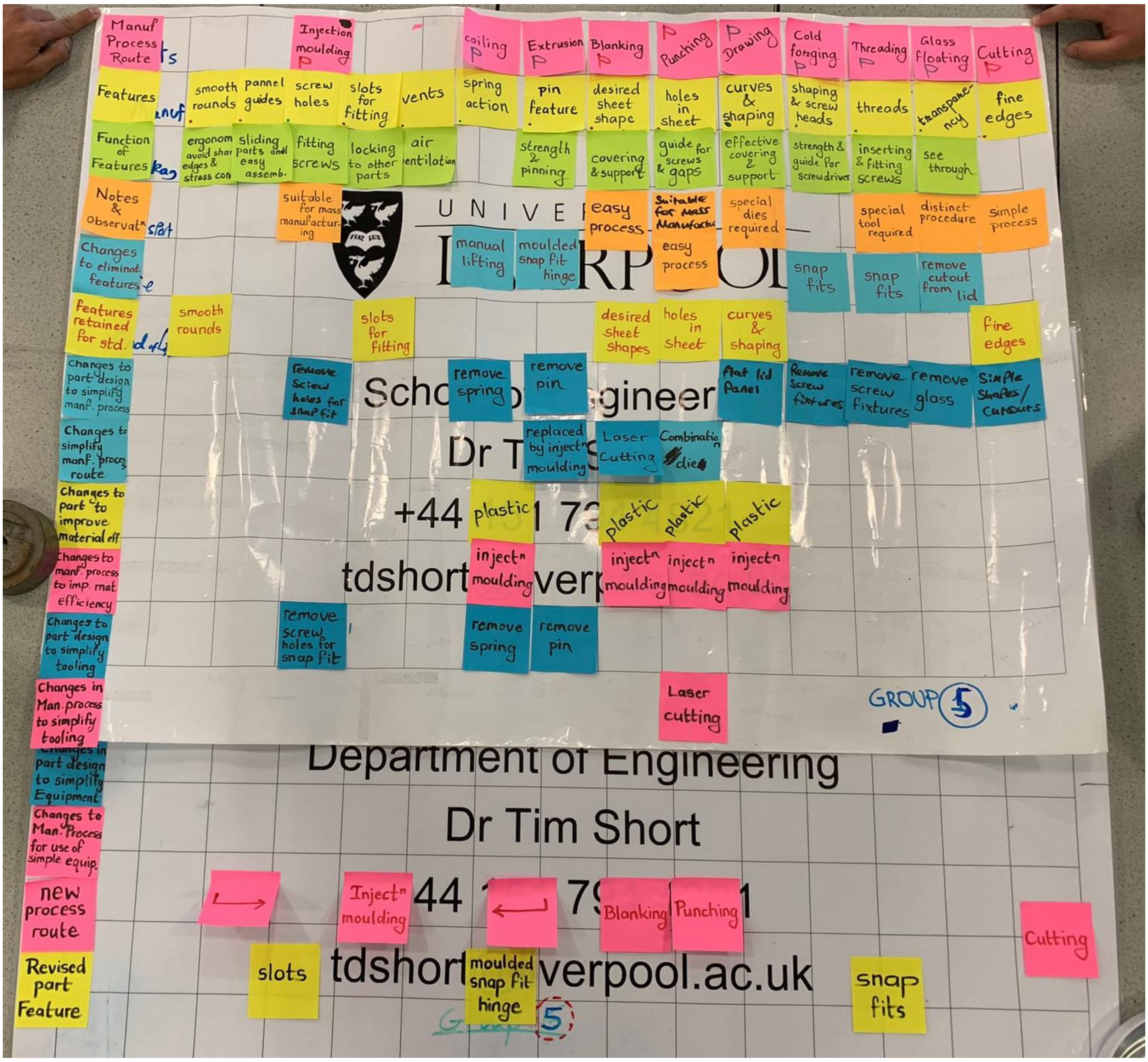

Figure 8: Picture of DfA matrix done in Lab

Colour Coding:

Key	Manuf process / Order	Features / Part	Changes in design	Essential Feature	Non-essential Feature
Colour Code					

Key	Processes	Manufacturing	Tooling	Equipment
Colour Code	P / P	M / M	T / T	E / E
Green implies 'try to improve', Red implies 'will not change'				

Phase 1: Collecting Information	Manufacturing Process Route	Injection Moulding P					Coiling P	Extrusion P	Blanking P	Punching P	Drawing P	Cold Forging P	Threading P	Glass Floating P	Cutting P
	Features	Smooth rounds	Guides for faceplate	Screw holes	Slots for fitting	Vents	Spring action	Pin feature	Desired sheet shape	Holes on sheet	Curves and shaping	Shaping and screw heads	Threads	Transparency	Fine cut edges
	Functions of Feature	Ergonomics, avoid sharp edges and relive stress concentration	Sliding parts and easy assembly	Fitting screws	Locking to other parts	Air ventilation	Open lid auto-matically	Strength and pinning action	Covering and support	Guide for screws and cut-outs	Effective covering and support	Strength and guide for screwdriver	Inserting and fitting screws	See through	Filter Edges
	Notes and Observations	Suitable for mass manufacturing							Easy process	Suitable for mass manufacturing	Special dies are required		Special tools are required	Distinct procedure	Simple process
Phase 2: Feature Reduction	Changes to Eliminate Feature						Manual lifting	Moulded snap-fit hinge				Snap-fit fasteners	Snap-fit fasteners	Remove cut-out from lid	
	Essential Features	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Features Retained for Standardization	Smooth rounds			Slots for fitting				Desired sheet shape	Holes on sheet	Curves and shaping				Fine cut edges
Phase 3	Changes to Part Design to simplify Man. Process Route			Remove screw holes with snap-fit fasteners			Remove spring	Remove pin	Combination Die		Flat lid panel	Remove screw fixtures	Remove screw fixtures	Remove glass	Simple shapes and cut-outs
Phase 4: Material Efficiency	Changes to Part Design to improve Material Efficiency					M	M	Plastic M	Plastic M	Plastic M	Plastic M	Plastic M		M	M
	Changes to Man. Process Route to improve Material Efficiency							Injection Moulding	Injection Moulding	Injection Moulding	Injection Moulding	Injection Moulding			
Phase 5: Tooling Simplification	Changes to Part Design to simplify Tooling	T	T	Remove screw holes with snap-fit fasteners T	T	T	Remove spring T	Remove pin T	T	T	T	Remove screw fixtures T	Remove screw fixtures T	T	T
	Changes to Man. Process Route to simplify Tooling									Laser Cutting					
Phase 6: Machine Requirement	Changes to Part Design to simplify Equipment	E	E	Remove screw holes with snap-fit fasteners E	E	E	E	E	Combination Die E		E	E	E	E	E
	Changes to Man. Process Route to enable use of simpler Equipment														
Result	New Process Route	Injection Moulding							Blanking	Punching					Cutting
	Revised Part Feature		Slots					Moulded snap-fit hinge							

Figure 9: DfM matrix

Additional Method: Assembly Efficiency Calculation

The DfA approach is applied in this method. This tool mainly focuses on providing quantitative analysis of the assembly process in terms of time efficiency considering the number of the parts to be assembled. The greater number of parts means more time to assemble or more time by single part compared to others leads to decreasing the assembly efficiency. By looking at the data, improvements to the part can be suggested. Here, step by step process of assembly of lid was recorded and assembly efficiency calculation is done for lid sub-assembly as,

To know the extent to which the efficiency level of the assembly of a product can be used the following formula[4]:

$$DE = 3 \times \frac{NM}{TM}$$

where,

DE = Design efficiency

NM = Minimum number of parts theoretically

TM = Total assembly time of all parts

No	Part Name	Amount
1	Hinge Spring	1
2	Hinge Cover	1
3	Hinge Pin	1
4	Lid	1
5	Countersunk Screws for Hinge	4
6	Glass	1
7	Latch	1
8	Lid Inner Faceplate	1
9	Countersunk Screws for Faceplate	9
10	Filter	1
11	Filter Cover	1
	Total	22

Sequence	Assembly Process	Time (second)
1	Align and insert spring into hinge cover	10
2	Slide pin into Hinge assembly	15
3	Place hinge assembly into lid	20
4	Screw Hinge assembly to lid	70
5	Place the glass in lid	5
6	Align the latch wrt screw holes on lid	10
7	Align and place faceplate on lid assembly	5
8	Screw faceplate to lid assembly	170
9	Insert Filter	10
10	Insert and attach filter cover	20
	Total	335

To calculate production assembly efficiency,

$$DE = 3 \times \frac{22}{325}$$

$$DE = 0.197$$

This implies that the assembly of the lid has efficiency of 0.197. Closer the calculated efficiency to 1, better the assembly procedure is. In this case, screwing the parts in place take lot of time which hampers the efficiency. Also, the parts can be designed to fit directly without need to align and hold them properly. This assembly process can be improved to make it simpler. New design or part reduction will definitely help to ease the assembly.

Final Design

The final design presented here is reckoned with previous design suggested in DfE. The final features are now improved with consideration of DfMA analysis. Other few changes are kept same from the environmental aspect. The lid had many parts, made of different materials, taking considerable time to assemble and processes to manufacture. This new design is aimed to reduce that while retaining the basic functionality.

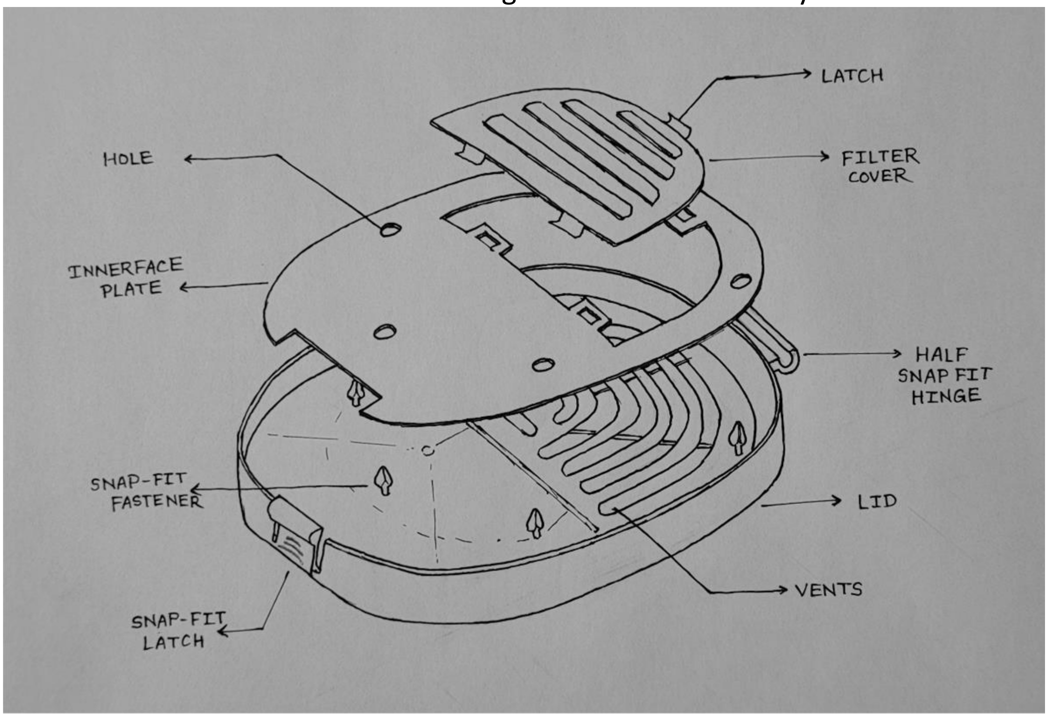

Figure 10: Exploded View of Redesigned Lid

First improvement is for fitting the interior metal faceplate to the main body of the lid. The snap-fit fasteners are used to connect mild steel sheet to propylene lid. These fasteners are moulded with the lid. The interior faceplate has holes into which these snap-fit fasteners slide and fix. As odd number of fasteners are used, there is only one way to assemble this. This will also hold the filter in place with the plate and can be easily removed for cleaning. The metal faceplate is still used because lid comes in contact with hot oil fumes, it can omit toxins after reacting at high temperature or get damaged over the time. So, keeping the metal part inside makes it sustainable.

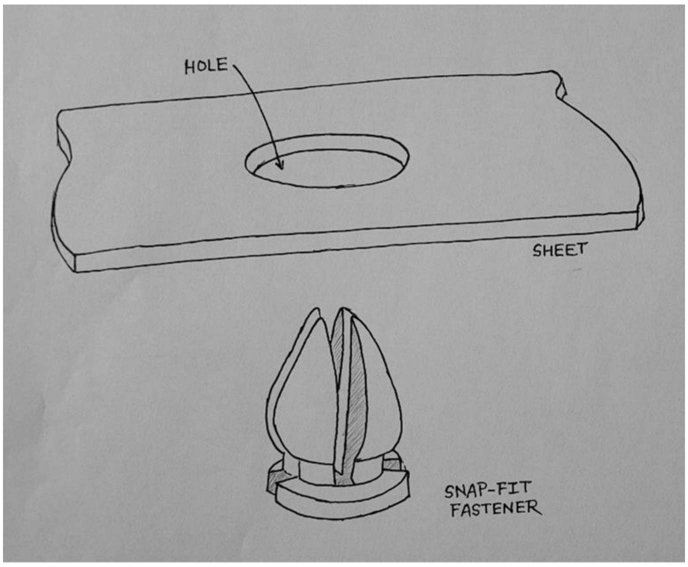

Figure 11: Snap-fit Fastener Design

Next area of change is hinge. Previous spring-loaded hinge is replaced with snap-fit hinge. Using snap-fit hinge, lid will be still attached to main body and function properly. It is moulded with the main lid; so, no extra process is required. The half parts will snap on rod moulded on lower body.

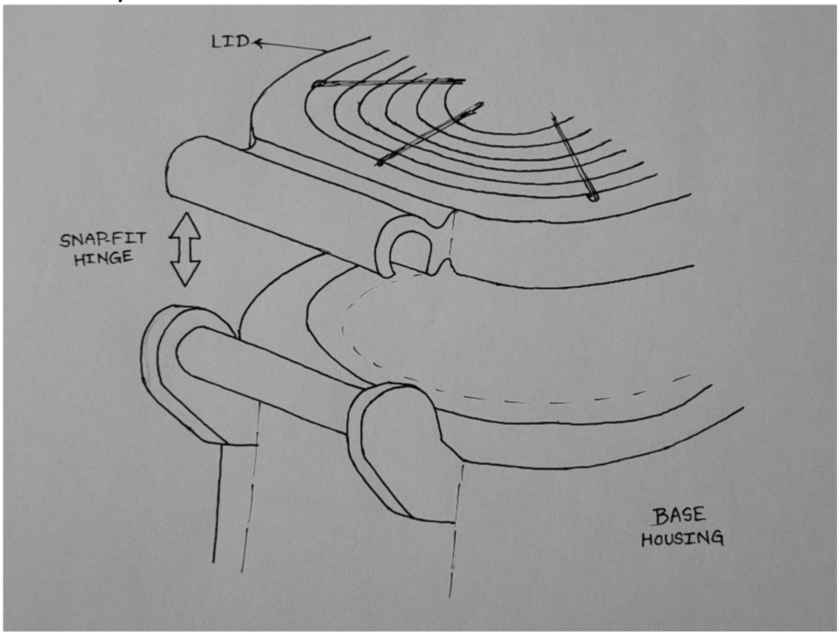

Figure 12: Snap-fit Hinge Design

The latch in original fryer is removed with flexible snap-fit lock. Instead of having big and auto-opening lock, small but useful lock was used. Snap-fit hook allows to fit easily with minimal effort and easy to open by pressing in the hook and pulling up the lid. As it is small, it can easily fit in between basket handle. The locking part serves minimum purpose but is good feature to have for safety reasons.

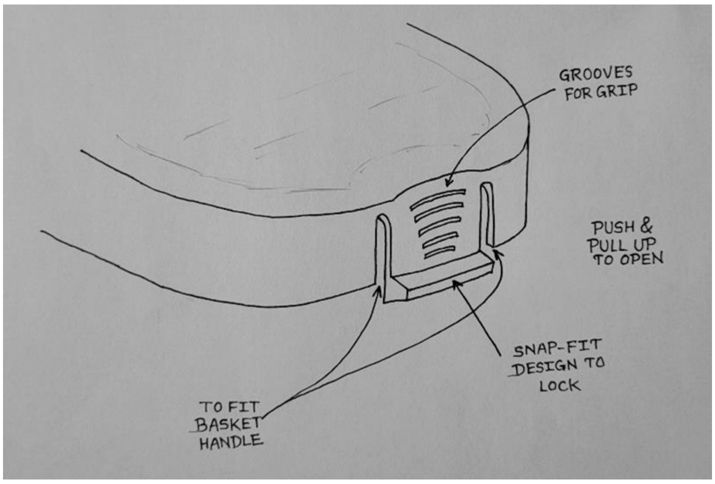

Figure 13: Snap-fit lid lock Design

Another change is regarding the glass in the lid. It is removed from the design, eliminating the transparent window feature of the lid. As it is not advised to close the lid while fryer is in use and when oil is hot, having glass window to see inside idle fryer severs negligible functionality. Removing the glass will not hamper the main function of fryer, so it is removed from final design and lid is solid filled instead of the window. This also reduces the weight of the lid, making it easy to open manually.

Discussion

The new design is aimed to improve the fryer on all grounds, considering suggestions from DfE, DfA and DfM. The changes are done according to the suggestions from the application of the tools. The first change of using snap fit fasteners is mainly to make assembly simpler. No screws are needed so it is easy and quick to fit the interior faceplate to lid. Eliminating screws also saves material, manufacturing process like threading and energy. Although it is slightly difficult to remove from snap-fit, makes assembly and maintenance much simple.

The snap-fit hinge does not provide the spring action, but it saves lots of assembly steps and manufacturing processes. The trade off is move effective as it is easy to detach for cleaning the lid and maintaining. It can be moulded with lid via injection moulding process. Many parts like pin, spring, hinge cover, screws for it, are eliminated saving the time to assemble and manufacture. Next change is Snap fit lock. This is also moulded with the lid and made of plastic, so no metal latch and screws for it are required. The difficult assembly process of aligning the lid and then fixing it with faceplate and then screwing is eliminated, making it easy to produce. Punching and bending process to make latch is also eliminated, saving the metal.

The glass is removed to save the manufacturing process as it uses completely different manufacturing processes and has minimal function. Although this part is easy to insert, glass is fragile and difficult to handle. Removing one feature is critical as it has purpose in final product to see through when it is not in use, but in overall sense it does not add much to main functionality of fryer. So, from both DfE and DfM aspect, it is eliminated. A summary of changes is in following table. It gives overview of motivation behind the changes and which tool helped to improve these changes. So that TDS Appliance Ltd. can consider for future development of the fryer.

Change proposed	Reason	Df-E/M/A driven
Snap-fit fasteners to attach interior faceplate instead of screws	Reduce part count, Improve assembly process.	DfA
Replace spring hinge with snap-fit hinge	Reduce part count, Reduce manufacturing process, Simplify assembly.	DfMA
Replace latch with snap-fit lock	Reduce extra material, Avoid complex assembly.	DfEA
Remove glass from lid	Reduce extra material, Avoid extra manufacturing process, Improve handling.	DfEM

Figure 14: Summary of changes in Design

Conclusion

In conclusion, DfMA methodologies were applied to the Cookwork's Deep Fat Fryer to improve the overall design by reducing the part count, using less material, enhancing the sustainability, simplifying assembly steps and eliminating manufacturing processes. The new design with all the considerations and enhancements is proposed to TDS Appliances Ltd. to produce efficient fryer which will be eco-friendly, cost-saving, easy to maintain and repair, simple to assemble and manufacture while being more sustainable. The part count is reduced to ease the assembly process. From the application of tools, the snap-fit connections eliminated the need for screws and snap-fit lid lock enabled easy operation while saving manufacturing of extra components. Critically, some features like spring action and glass are omitted from final design to save material and additional manufacturing method, considering that their removal will not affect the main working of the fryer. So, the company would be benefited from incorporating the design.

For future, prototyping, testing and cost analysis can be done to finalize the design for production and practical applications. Heating element and packaging also can be improved for economic reasons. Better quality materials can be selected, and recycling of the product can be standardized for improvement. Overall, DfEMA tools helped to analyze and improve the product in many aspects. Resulting design of fryer will lead to sustainable, ecofriendly and economic path providing better customer service.

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