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Reflective Project Report
Group Project ACMA5009

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1 Abstract

This paper takes a detailed look at the development and application of new lean-based design techniques within the design department at Bisley. This report looks at how lean thinking was used to develop and improve the DFA (Design for Assembly) characteristics of products already in production. The project initially set out to decrease the sub-assembly time and average of 20%.

During this process, the methods used within the design process were also evaluated using lean methodology. Technology such as preset dynamic modelling and parametric modelling was explored to improve and streamline the speed at which similar designs based on traditional products can be created and BOM created in the future.

This project experienced success in the primary goal of reducing the time needed to fit each panel ready for final assembly. It was identified that the main obstacle was the number of fixings used in the design, and consequently they were the primary target for design out. The reduction of fixings across the product range led to a reduction in timing of 33% on average. However, there were some problems through the project. The time which it took to complete the project was longer than expected; the challenge to create and utilise parametric modelling met unexpected challenges. These challenges led to more work content than expected. Additionally, the scope of establishing parametric models had to be scaled back to the creation of individual components which are common across product.

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2 Introduction

2.1 Project Background

This report will broadly focus on applying and integrating Lean thinking and methodology within the design process at Bisley. More specifically, this report will focus on one project orientated towards this overall goal, in which the design of the 'Pren' product range was assessed and improved through lean thinking.

The integration of lean thinking in a design process stemmed from broader improvements being made elsewhere in the company, to purely manufacturing systems. Lean thinking was already in use for its more traditional role in improving flow within the production environment.

It was proposed that lean thinking and methods of gradual improvement could be applied to how products are designed. The design has an outsized impact on the cost, with an estimated 70% of the cost of a product being baked into it at the design stage (Knowledge Sharing Centre, 2024). To this end, the Pren was chosen as the first product range to be reformed through a lean methodology.

The aim of the project was to reduce the time to complete the final assembly of panels by 20%, only through design alterations. The deadline of the end of the year as of the start of October was put down to assess the feasibility of repeating this process across other product ranges. The application of lean to the design process has continued from this contained project and is still ongoing.

2.2 Why This Project?

This report aims to focus on a project that could have the potential for real impact. A project which is still ongoing, as opposed to a completed project from the past, has the potential to affect an ongoing iteration and improvement of the current methodology. An entirely reflective report, despite being able to look at the final outcome of a project, will rely on analysing techniques which have been evolved and moved forward by those using them at the time. Additionally, this report needs to focus on recent events, avoiding as much as possible any bias inevitably associated with reflecting on projects too far in the past.

This project supports these aims well since the evolution of product design within the organisation is still ongoing beyond the scope of this project. Also, this project has a record to look at, which is significant, as the factors which have got the project this far will be key to affecting its future. This combination of continuous past and present data allows for a detailed and analytical reflection of a project, influencing forward-looking adjustments and improvements in the near and far future.

This project also revolves around Lean thinking. Lean and related methodology has a significant body of research and easily accessible resources to cross-examine with. Talking about a Lean-orientated

project gives this report plenty of opportunity to use accurate and trusted sources to look at how these theories and concepts have been executed in practice.

2.3 Report Gantt Chart

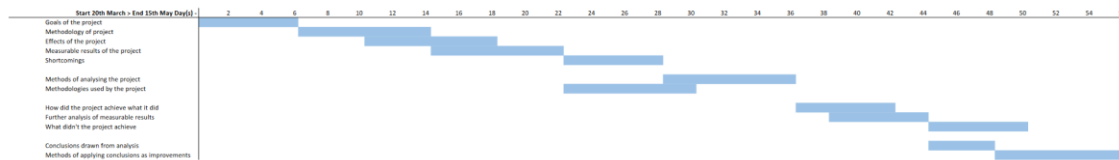


Figure 1 Image of Report Gantt Chart

Above is Figure 1, a Gantt chart showing the planned progress of this report. This Gantt chart displays a timeline for:

Detailing the facts and results of the project in question. This is scheduled across a 28-day period; the majority of the report will rest on an important grounding in what the project is, how the project has been carried out and the results of this so far.

Next, a literature review will be completed to inform how the project will be evaluated and provide research to compare the methodologies used so far in the project against how those methodologies should be applied. Additionally, the research should provide details of other possible methods.

The next section will combine both the details of the project and the research around the techniques used to assess the project. This will cover the effectiveness of the achievements so far and then apply these methods proactively. Through this forward-looking application, changes will be proposed in conjunction with the current shortcomings.

These findings will then be concluded, and methods of applying these conclusions will be discussed.

3 Project Overview

3.1 Project Timeline Gantt Chart

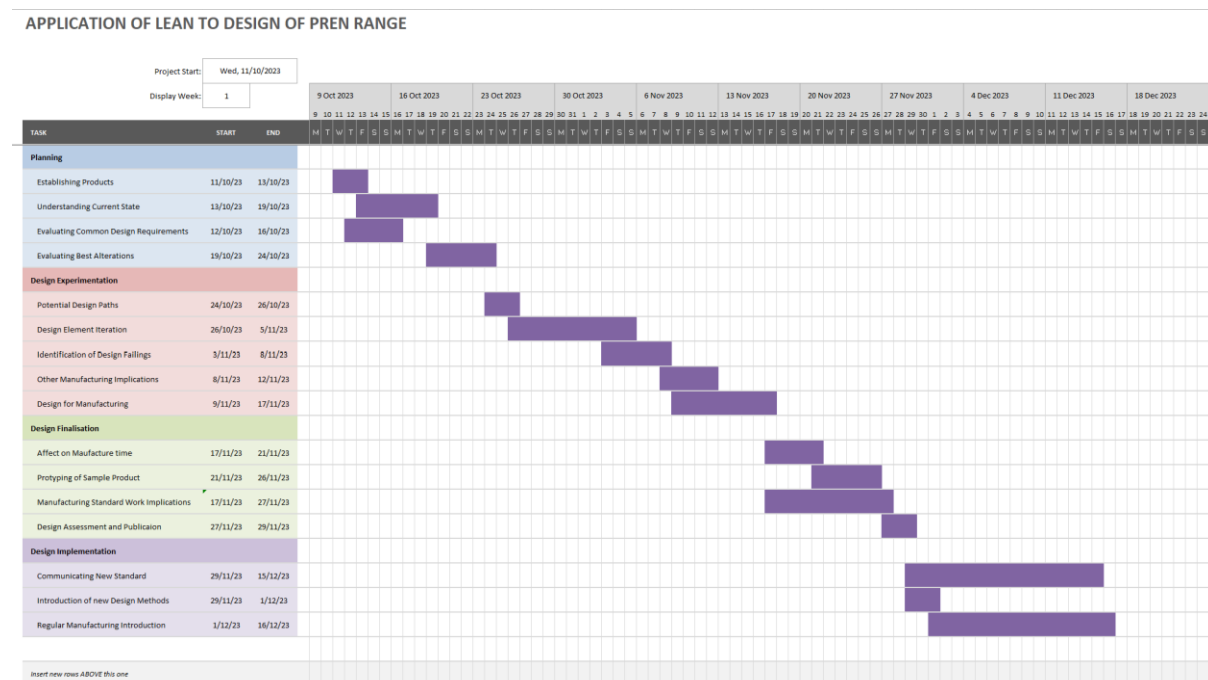


Figure 2 Image of Project Timeline Gantt Chart

First, the project's scope needs to be laid out and initial research carried out; along with the current state understood. Understanding the current state of the project allows future decisions about direction and design strategies to be best informed. Along with this, a generic plan will form and the types of alterations that will take place will be decided upon.

Next, the choices made during the planning phase will be expanded upon and fully explored using CAD software and predictive tools. Each design element of these iterations are explored and the optimal ideas of each will be cross-examined with manufacturing needs.

The design is finalised through prototyping and the exploration of standard work changes. The models used to make decisions up to this point are refined using real-world experiments designed to express and explore the voice of the customer. Feedback from, and inclusion of production personnel is key at this stage. Without the successful inclusion of these members, the successful forming of a coalition is key for the change to be lasting (Haas et al, 2020).

Finally, the design gets implemented into production. This process is over several weeks, and elements of this phase are present throughout the entire project. Design work is also carried out to apply the improvements across the entire range, and the standard work refinement is introduced to regular production.

3.2 Goals of the Project

The overall goal of the project was established based on the main production bottle-neck when assembling units. The fixings must be manually attached to each panel. These include dowels, CAMs, pillars and other items such as door handles and locks. This process is a mid-assembly process between the panels being cut and the final assembly. Due to the fact that many panels, sometimes as many as a dozen or more, are needed per unit, most of the labour cost in any unit is in this stage.

From this, the project aimed to reduce the time to build by 20%, without adding workload for production. Due to this, design changes through CAD to reduce fixings were identified as the main method of change during the early stages of the project. Lower fixing count will reduce panel processing and panel assembly times; additionally, final assembly times would reduce slightly as well, with fewer fixings to secure and quality check downstream.

In lean terminology, the reduction of fixings is waste removal/reduction targeting waiting, defects, extra processing and excess inventory (Voehl et al, 2013). Any excess fixings being used by the product is overprocessing of the product. The reduction of overprocessing aims to reduce total processing time per panel by 20%, from the current time of approximately two minutes. When these design changes are taken into effect, the project further aims to work with production to alter the standard workflow of units through the line. Rebalancing workflow will help to maximise the savings in time, and therefore, labour.

Secondarily, in addition to tackling muda, the project has aimed to better understand processes that do add value, and find ways to better perform those functions. Through this, the project also aimed to standardise the method of work across multiple designers. This can be achieved by introducing design standards for new products; and improving how and where fixings are placed. This will ensure new product ranges in the future will benefit from the waste reduction from this project. Through developing standard methods of design work, the project aims to identify and address inefficiencies in individual workflows (Lorenzo, 2008); and in so doing, discover the best method of performing known design requirements and to apply them uniformly.

3.3 Project Methodology

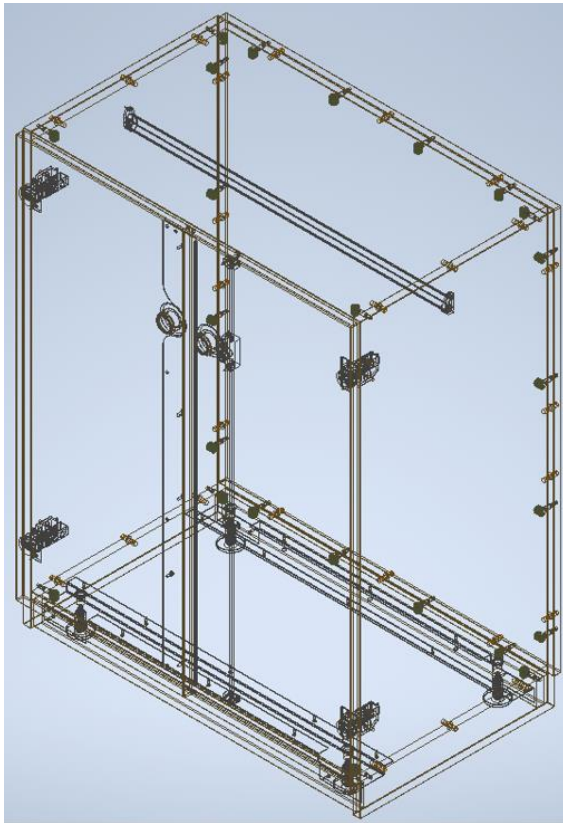


Figure 3 Example of Product Initial State

In this figure, there are 30 and 32 fixings respectively in the back and side panel alone. Now it was necessary to explore a wide variety of possibilities and identify what fixings were wasteful. With the use of CAD-generated BOMs based on product master models, many design solutions were able to be generated and the various advantages were considered. These models generated BOMs which generated expected timings based on real-world data of timings. The initial timing of the side and back panel assembly is shown in Table 1 below. This provided a basis for design iteration.

	Fixings Count	Total Assembly Time (s)			Average Time	Time Per Fixing
		Measurement 1	Measurement 2	Measurement 3		
Side Panel	32	127	140	110	126	3.93
Back Panel	30	113	128	109	117	3.89

Table 1 Table of Initial Assembly Times

These design iterations then need to be judged against manufacturability, form and function. These requirements can more broadly be categorised as the voice of the customer within the product. The first consideration is the strength of the product. The unit's strength comes from the strength of the fixings holding it together, and these must be able to withstand the weight of the unit itself, along with any load the customer might place within the unit. However, most units that fail do so during transport

to the end user, as stresses can be applied to the unit it wouldn't usually experience during daily use. The respective designs were analysed for carcass strength and rigidity. This is most prevalent for tall and thin units, which might be prone to being damaged by twisting moments damaging panels due to a lack of fixings present to share the stress.

Jointly, the manufacturing needs are considered in conjunction. The ability of fixing points to be drilled, and the cross-compatibility of larger fixings with edge-band selections are some of the drilling considerations which restrict where fixings can be placed on a panel. Additionally, construction might be complicated by panels, shelves and hinges obscuring or blocking hole positions. The variety of internal configurations across the range introduces design requirements hidden from the customer.

These designs varyingly decreased the number of fixings in the units. These designs are expressed through a master model, able to take dimensions and re-size the unit carcass as required. Each design obeys a series of rules about the number, position, type etc of the fixings to be used based on the size of each panel. The size of the panels is determined by the programme based on the size input and known factors such as material thickness. This programme, for future designs, greatly increases design cycle time for adding to the product range.

In addition to fixings, this project looked at the standardisation of cutouts for other, more complex components. This tied to the secondary objective of the project; to standardise the workflow of the design and engineering team. All product ranges use a highly varied range of locks and other user-driven fixtures. For many, they are customer-specific or product-specific, and few standards for position or cutout shape were consistent across products. Some of the more common variants of lock are shown. This is a key customer requirement, and consistency across the range should be assured through uniform design.

Pren Specification Notes

Locking Options

All Pren Two Door Cupboards and Wardrobe Units are listed as non locking.
All Pren lockers are listed with AB locking.

For the below alternative locking options on Two Door Cupboards and Wardrobe Units change 'NL' to the relevant locking suffix.

On locker units change 'AB' to the relevant locking suffix.

For example:

For **AB** lock on Two Door Cupboard - SC08075020**N** , becomes SC08075020**AB**

Please note: Pren Wardrobes, Cupboards and Drawers are only available with AB, M2 or M3 locks as standard.

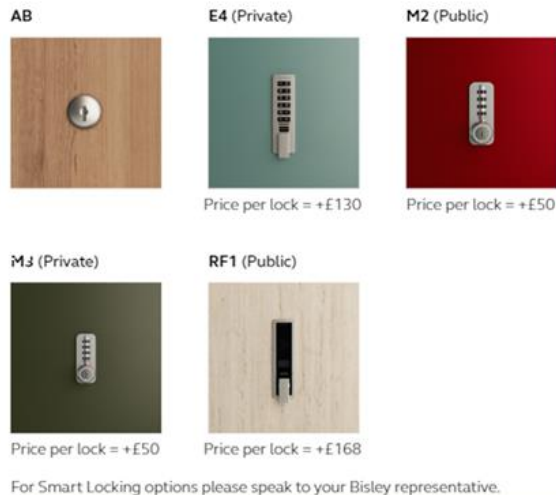


Figure 4 Product Range Lock Options Example

The method used to achieve this was to look at the creation of a unified document to maintain aesthetic uniformity, taking into account the body of work already in existence.

Finally, the format of the experiments used to assess the success or failure of various designs must be uniformly applied. In this case, panels using the new design were timed, with multiple repeats, as they went through the line. In addition to quantitate data, it is essential any such operation also takes qualitative feedback from those doing the work. This feedback is crucial for informing ergonomic and skill requirements straight timing fails to provide. Poor ergonomic design reaches out not only to the final product but at every assembly stage. Operators, during this mid-assembly stage, shouldn't need to reach or stretch across the panel in order to complete the task.

3.4 Project Results

The central results of the project were the timings of the mid-assembly process. These were generated based on the repeatable experiments of both back and side panels; these experiments were based on one of the largest Pren units. The original design, as above, had 32 fixings in the back panel. The successive designs took fixings from the panels in ways which attempted to maintain the unit's strength. The 3 competing designs were then selected based on experiments comparing each other,

their theoretical timings, and the original timing of the Pren range. Shown in Table 3 is the result of the selected design. The average time per fixing has increased, as the other steps in the assembly are now a larger proportion of the process.

	Fixings Count	Total Assembly Time (s)			Average Time	Time Per Fixing
		Measurement 1	Measurement 2	Measurement 3		
Side Panel	20	79	86	90	85	4.25
Back Panel	18	72	80	85	79	4.39

Table 2 Table of Measured Timings

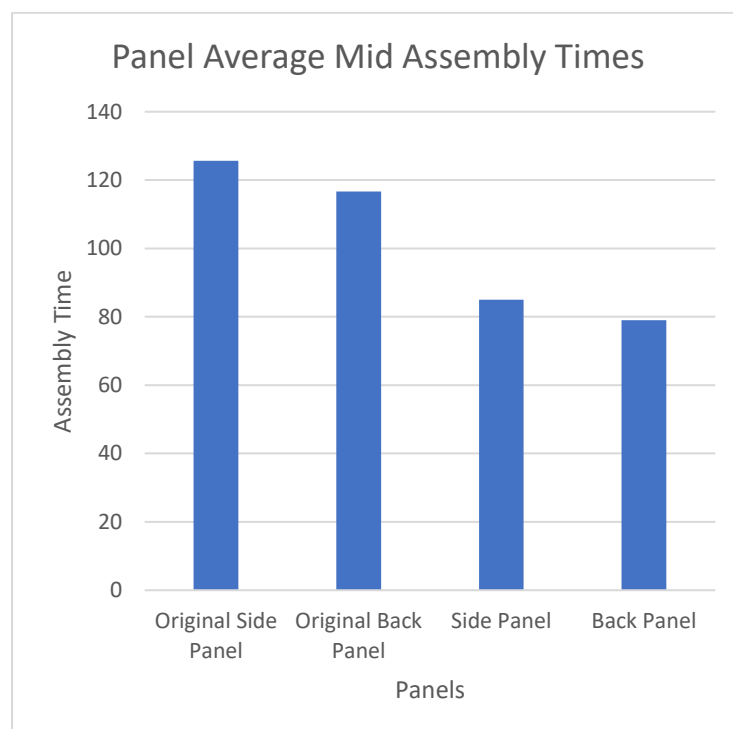


Figure 5 Graph of Measured Results

The first design has 14 fixings, however, these were placed in locations which weren't ergonomic to access on large panels; this significantly slowed the process due to the operator struggling. In contrast, the unit above with the lowest timing had 18 fixings in the back panel, a reduction of 44%. In addition, the new timing was 33% reduced from the original panel design. This reduction achieved the main objective of the project, which was to achieve a 20%-time reduction in installing panel fixings. The design of the new product range is shown below.

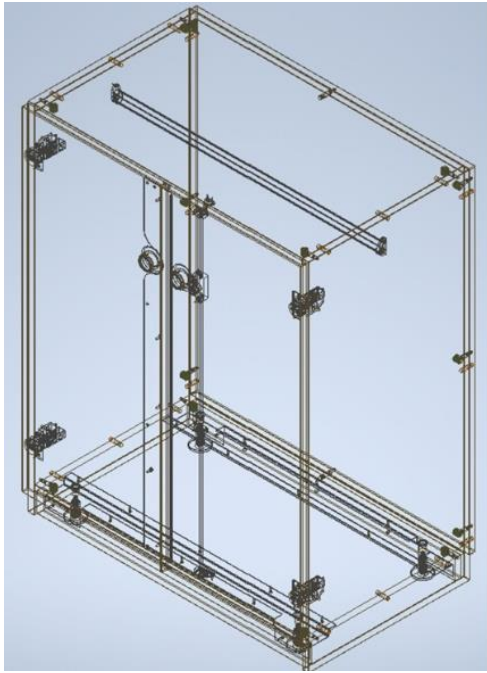


Figure 6 Example of New Design Standard

This final design uses automatic rules through parametric models to generate new carcass sizes. In units up to 1500mm high and 800mm+ wide, use 6 pins, 6 dowels, and 2 permanent dowels. Use 3 pairs of pins and dowels per side panel, and one permanent dowel in the top panel and one in the base panel. In units over 1500mm high and 800mm+ wide. Use 8 pins, 8 dowels, 2 permanent dowels. Use 4 pairs of pins and dowels per side panel, and one permanent dowel in the top panel and one in the base panel.

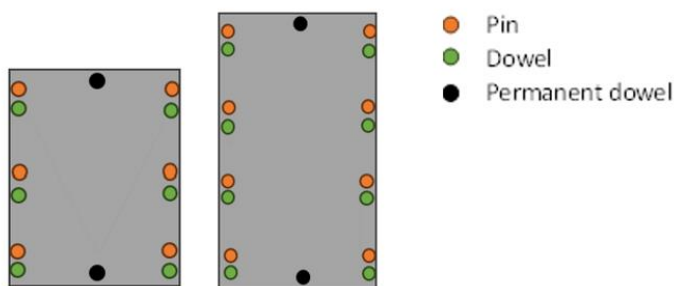


Figure 7 Diagram of Fixings Standard Example

The secondary objective of the project was to use the Pren re-design as an opportunity to create design method standardisation. This has taken the form of the parametric models, and the rules as stated above. The result of this has been a marked increase in the rate of designs which can be turned around through the SR process. Moving forward, these rules are going to be applied to other product ranges. This is a currently ongoing project within the design team moving on from these results.

3.5 Project Shortcomings

Through the course of the project, of course, there were challenges and a variety of areas in which the project fell short of established goals, or could have achieved these goals in a more efficient manner.

The primary area in which the goals of the project could have been achieved with a more efficient method was the development phase. Most of those who contributed to the project felt time and effort was wasted on topics, project details, and the technical solution to problems which ultimately didn't affect the outcome of the project. It was generally agreed this was during the experimentation phase of the project.

Engineers in the team were split to work on many design solutions in order to cover as much development as possible. In reflection, it was seen that if this work had been completed linearly (or step-by-step) many design possibilities would have been removed from future work as they became obsolete. It was proposed that through a more effective distribution might have reduced the total workload through a focus on eliminating 'wasted' work content.

Another challenge faced by the project was the implementation and use of parametric designs. Parametric designs are excellent at eliminating design workload in the creation of design iterations. These parametric models can instantly re-size existing models, following set rules and guidelines to calculate metrics like fixings, clearance, tolerances etc.

However, many designs contain unique or novel elements that an automatic design generator cannot account for. Further to this, once the model has created commonly used sizes, the model's use begins to tail off. Due to these reasons; after the development and implementation of the models from this project, they were not regularly utilised. It has been, since this project, recognised that the design of this software isn't fit for purpose with most design requirements.

Additionally, these models require a huge investment of time and resources in order to create and keep updated to standards for a given design or product range which might change in unknown and expected ways.

5 Literature Review

5.1 Project Analysis Methods

Root cause analysis (RCA) is a systematic method for identifying the underlying reasons behind problems or incidents within an organization. Accidents/management failures are from a chain of related events; from understanding the chain of events we can assess their cause (Leveson, 2011). Root cause analysis (RCA) is crucial in various fields, including engineering, healthcare, aviation, and manufacturing, where even minor errors can have significant consequences. By understanding and interrogating root causes, organizations can implement effective corrective action beyond the immediate problem to improve processes, and in the long term address the underlying causes of failure (Lorenzo, 2008).

A root cause analysis can be carried out using a variety of methods. Amongst these matrix diagrams, fault-tree diagrams (Andersen et al, 2006) or a fishbone diagram and causal map (Bjørnson et al, 2009). These techniques can be used to uncover root causes, develop corrective and preventive actions, and implement solutions.

Ultimately, it empowers organizations to make informed decisions, enhance safety and quality, and optimize processes to achieve better outcomes and sustained performance improvements over time.

Value chain analysis is used to identify areas where competitive advantages can be gained. It involves breaking down the company's operations into primary and support activities to understand how value is created at each stage of the production process (Dawson, 2024). Value Chains include raw material suppliers, logistics and transport, component producers, final assembly and wholesale / retail (Londe, 1994). These activities are directly involved in the creation and delivery of a product or service to customers. Each of these steps are broken down in detail; allowing cross-comparison. It is increasingly important to map out and document the value chain (Qing Li et al, 2019). Support activities, on the other hand, include activities such as procurement, technology development, human resource management, and infrastructure, which provide necessary support to the primary activities. By analysing each activity in the value chain, companies can identify opportunities by examining interactions between different players in an industry (Zamora, 2016). For example, they may find ways to streamline production processes, negotiate better deals with suppliers, improve customer service, or invest in technology to enhance product quality.

Performance analysis is a structured approach to evaluate the effectiveness of systems, processes, or projects by comparing their outcomes against predetermined criteria or benchmarks. Clear objectives

and criteria must be defined to guide the analysis. These criteria shouldn't be chosen for simplicity (Oh, 2001), and need to reflect all aspects of the project. For instance, in this manufacturing scenario, the objective is to enhance production efficiency, with criteria including cycle times and defect levels. PA uses performance to derive practical suggestions about the topic being assessed (James et al, 1977).

Interpreting results involves assessing how well the system or process aligns with the established criteria. Identified strengths and weaknesses inform the development of future projects, aimed at addressing deficiencies and capitalizing on strengths. Continuous monitoring mechanisms throughout the span of a project ensure the suitability of the end result (Zhiguo et al, 2022), and this will help guide iterative improvements. This cyclical process fosters adaptability and responsiveness to changing circumstances. Ultimately, the goal is to optimize performance and achieve organizational objectives efficiently.

5.2 Project Methodologies

Muda, a Japanese term for waste, is a fundamental concept in lean manufacturing and continuous improvement. It refers to any activity during the production process which doesn't contribute to product success (Marhani, et al., 2021). Identifying and eliminating muda is crucial for enhancing efficiency, reducing costs, and improving overall quality. One element of waste is over-processing, which this project has focused on. Overprocessing is the performance of extra work in a process which isn't required by an end user (UBIsense, 2023).

In this context, overprocessing is represented by the excess fixings used to create the product. Beyond the needs of the customer, any additional strength the product has is a waste, due to the time and components needed to give that strength. The identification and removal of non-essential fixings, using the Lucas methodology, could also be applicable to identify 'muda' in the design. These non-essential parts are 'b' parts, and are those that the product can function without (Ismael, et al., 2021).

$$Ed = \frac{\alpha}{(\alpha + \beta) * 100\%}$$

Figure 8 DFA Design Efficiency Formulae (Ismael, et al., 2021)

This could be used as a framework for measuring the efficiency of an assembly design, where 'a' parts are essential parts, and 'b' parts are non-essential parts. This formula can be used to compare the final design against the initial design. Additionally, this provides an alternative quantitative measure alongside the number of fixings to use to analyse the project's successes.

Value Stream Mapping (VSM) is a fundamental tool in lean manufacturing, designed to improve operational efficiency by identifying and eliminating non-value-added activities within production processes (Singh & Sharma, 2009). It entails visualizing the flow of both material and information from raw materials to the final product, providing a comprehensive overview of the entire production process (Nasution et al., 2018). This visualisation can be achieved by mapping every stage in a process to understand how value flows through a business.

VSM is not confined to manufacturing industries but has also been applied in sectors like healthcare, logistics, and services (Salsabilah et al., 2021). By extension, this review should look to apply this technique outside of the traditional manufacturing environment to the flow of information.

6 Project Analysis

6.1 Project Successes

Value chain analysis involves breaking down the activities of the project (Dawson, 2024) to get a better understanding of which elements of the project were successful.

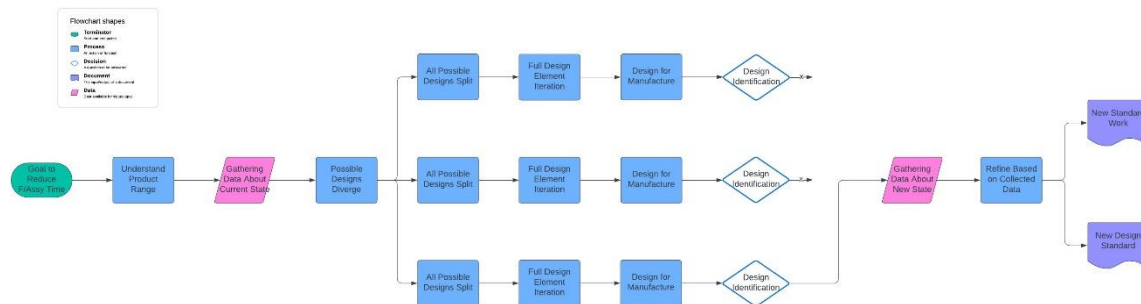


Figure 9 Design Process Value-Chain

The value chain used in the creation of design standards in this project is shown above. This process flows from the design goal, in this case, a 20% assembly time reduction, broadly to planning. Here the range of the project was understood to be around the fixings evident within the design. This understanding is the basis for the rest of the project builds from. The team used multiple methods, both analytical and qualitative, to come to the understanding that fixings needed to be the focus of this project. The freedom to approach the problem from a wide range of design options. This leads onto, and is part of, gathering data on the initial state. This data collection refines the design process. Here, the data allowed us to see that the other factors such as panel size, panel weight etc weren't introducing the highest variation in timings. This was highly successful in focusing the project.

Next, Several design options were explored by several members of the design team in parallel. Here, 3 are shown for illustration but in reality, there was several. Exploring these details to their conclusion through the use of CAD and simulated factors, including weight and predictive factors such as estimated time, provides key insights into the design variants. The project greatly benefited from the information shared between these, and in reality, the learnings taken at each stage were able to benefit the others through the next stages.

Measuring the new state of the identified design critically informed the methods and refinement which took place with the support of production personnel. The comparison focused on the goals of the flow of value of the project, as during the design stage value-adding decisions were secondary in order to facilitate the exploration of design possibilities. Additionally, the data collected highlighted how many of the assumptions made during the theoretical modelling were faulty; the theoretical value chain mapped above in reality included looping and redesigning stemming from the new state.

A performance analysis metrics from a project to allow monitoring of value through a process (Bjørnson et al, 2009). Through the course of this project, the number of fixings of each design was used to track the relative efficiency of each design. However, this metric was only applied to designs which still met other basic specified requirements of strength, fixing accessibility/ease of assembly. The project was successful in tracking multiple performance metrics in order to provide a concise and rounded picture for design comparison.

	Design Iterations							
	Initial	Iteration 1	Iteration 2	Iteration 3	Iteration 4	Iteration 5	Iteration 6	Final
Side	32	26	21	18	12	19	20	20
Back	30	24	22	19	15	14	17	18

Table 3 Fixings Count Through Time

Above is the tracked performance of the fixings count through each iteration of the design through the value chain. The project successfully used this information to track the performance of designs; additionally, this live data was used to inform each subsequent step in the process. The tracked performance wasn't exclusively listened to, and other considerations were allowed to influence each design. The flexibility in the central development meant at some points fixings were added, and progress wasn't perfectly linear.

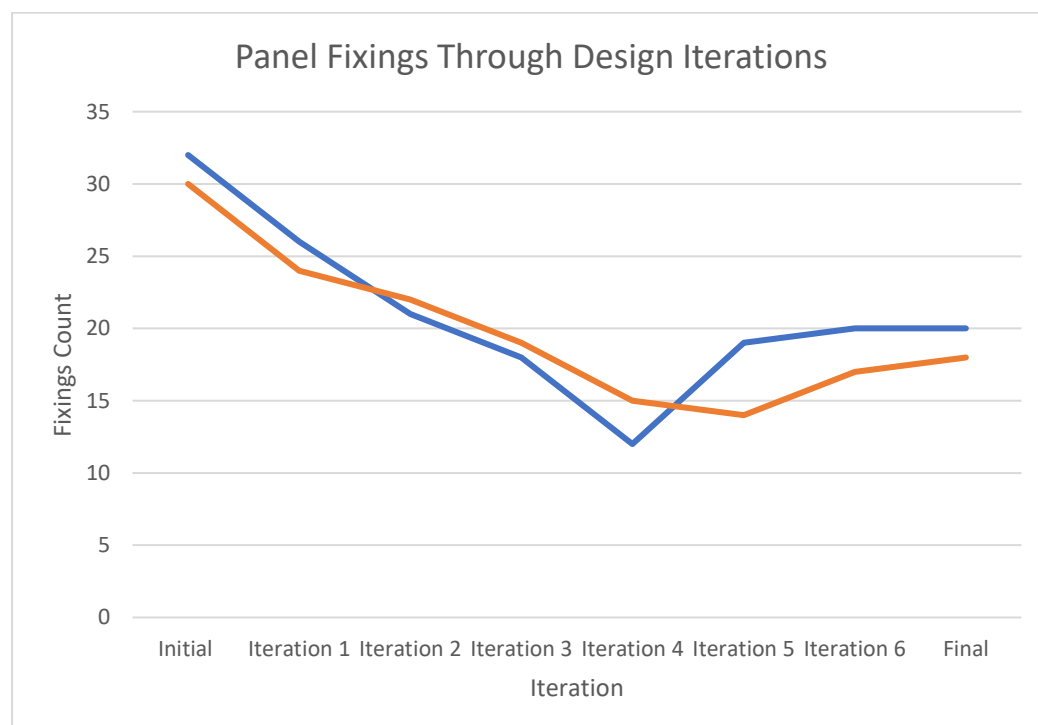


Table 4 Graph of Fixings Through Time

As shown through analysing the value chain and project performance metric, it is clear the project's success was derived through the flexibility afforded to the designs and allowing ideas to develop and successful elements to be incorporated into other designs. Strictly following a design methodology would have significantly affected the outcome of the project; the data and solutions from ultimately unsuccessful designs had a marked influence on the result. Without these, the project wouldn't have achieved the same design solution which was finally implemented.

6.2 Project Quantitative Results

To analyse the resultant design of the project against the initial design, a Design for Assembly (DFA) methodology can be employed to quantitatively compare the two assembly designs. When considering DFA, fasteners and fixings of all kinds are always considered targets for 'design out' (Velling, 2021); design out means parts within an assembly which are being targeted for removal, although this is not always possible. As such, these are 'b' type parts. Through this, we can say all the fixings are non-essential parts within the designs considered by the project. Through this, we can calculate the efficiency of the back panel assembly considered within the results section above.

	Non-essential parts	Essential parts (back panel)	DFA Efficiency (%)
Original Design	32	1	3.03
Final Design A	16	1	5.88
Final Design B	18	1	5.26

Table 5 Table of DFA efficiency for design variations.

The design the project used, due to having the lowest experimental timing, was design B. Despite having a lower theoretical efficiency, this result shows the success project achieved in balancing the principle of minimizing the part count of assemblies while maintaining easy and ergonomic access to the components to improve assembly. It was recognised that the benefits of lowering manufacturing costs through fewer parts and simplified inventory management were minimal when comparing designs A & B. This highlights how the project used multiple factors and measurement metrics to guarantee the design didn't suffer from objective-orientated tunnel vision.

6.3 Project Failings

The value chain shown above also displays some of the weaknesses of the project. The number of branches which appeared during the development phase of the project was both far in excess of the example of 3 and undocumented through the project. Across the design team who worked on this, each was allowed to explore the problem through their methods. Although this allowed the project to consider various possibilities, it also used development time on problems which ultimately proved to not be relevant.

The opportunity for growth in this area is to understand that the value generated at this stage is only within one branch of the value chain, and reducing the number and length of the other branches is critical to improving the method with which other development projects progress in the future.

Another problem faced during the project was the implementation of full parametric models. These models are highly efficient when implemented but are highly specific to a set design. When these models are relevant, they greatly decrease the design turnaround time. However, most requirements have some novel components. The elements in the failure of full parametric models include:

- Setup cost
- Limited use cases
- Programme Flexibility
- Design Saturation - As more designs are created from the same template, the number of new designs based on that product diminishes.
- Using these elements, and their implications, below is a causal map of forces influencing parametric model use within the design environment.

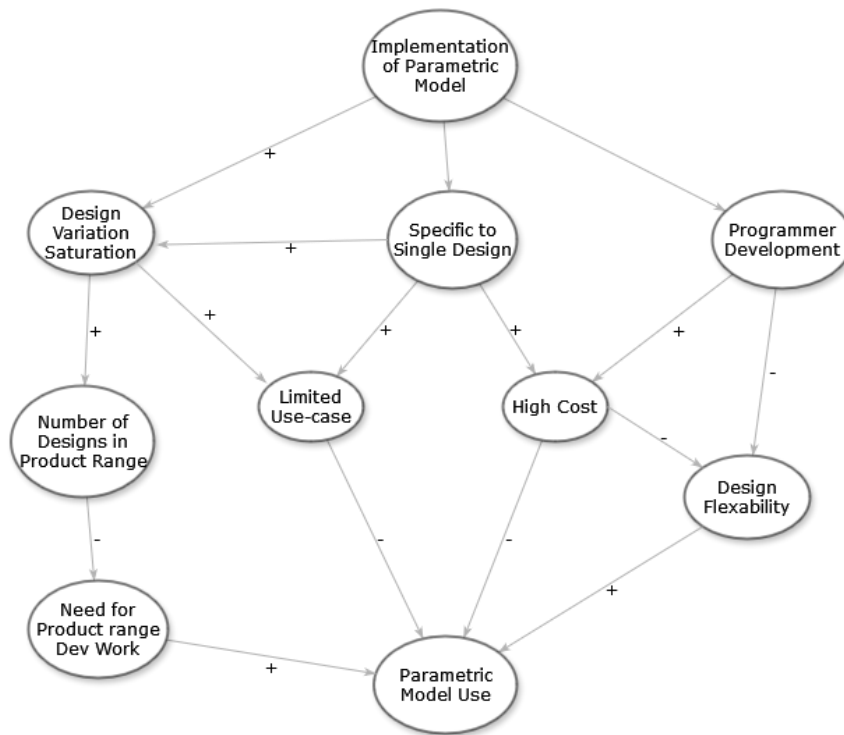


Figure 10 Causal Map of Parametric Use from Qualitative Feedback

These elements can be analysed individually in order to gain an understanding of the root causes affecting the model used, and how these elements can be addressed. How these elements interact with others within the map is shown with the use of arrows. A positive sign indicates a positive relationship; wherein the increase of the first increases the second. A negative relationship indicates the opposite, in which the increase of the first decreases the second. Through this, we can see the factors which influence decision-making regarding model use.

Due to its complexity, parametric models require team members with programming knowledge to create and maintain. This has knock-on effects on the ability of a design with a model to change freely and adds costs through time and skills to put in place. The specific use case of the model also increases the relative cost of model use. In addition to how narrow the tool is, the fact that a parametric model gets used less through time, as more iterations exist, combines with the specific nature of the tool to limit the use cases it can be applied in. This might include how many designs lend themselves to being modelled, and if there would be sufficient pay-back to justify the investment. Finally, the saturation effect means the model will slowly obsolete itself over long enough a period.

In order to remedy some of these problems, a model which was more general purpose would eliminate many of the issues on the left-hand side of the causal map. Such a model might be for common parts or part types, as opposed to entire products. These would have a smaller impact on design time but would be more economical and sustainable to implement.

7 Conclusion

In conclusion, the project was a major success on the balance. The project achieved the major goals it set out by the creation of a more effective design and the achievement of a 22% reduction in the time to complete the focused assembly process. This was achieved through design for manufacture techniques and the application of lean methodology not only to the production environment but also to a degree the design environment. The successes of this project include an effective gathering of information and the use of this data to accurately plan the subsequent design stages. Additionally, this was achieved through flexible processes which allowed effective consideration of a wide range of possibilities and pathways.

However, there were some issues with the project, mainly including the attempt to create parametric models of products to speed up development time and the excess workload at this stage which delayed the later stages. It also reduced the focus of the project at the end, and negatively impacted the ease with which the project transitioned to production and experimentation. In order to learn from these difficulties, they were analysed using the established value-chain and root-cause analysis techniques.

The results of this indicated how projects might avoid similar delays in the future. In replacement of full parametric product models, dynamic-part models might be used to achieve some of the effects this was looking to achieve. Along with being a smaller, more cost-effective step towards full automatic models, these wouldn't suffer from many of the setbacks suffered in this project. Also, a central focus for future projects would be the elimination of wasted development work through a more controlled, linear and process-orientated design phase.

8 References

- Andersen, B. & Fagerhaug, T., 2006. *Root Cause Analysis: Simplified Tools and Techniques*. United States, Milwaukee: American Society for Quality, Quality Press.
- Anon., n.d.
- Bjørnson, F. O., Wang, A. I. & Arisholm, E., 2009. Improving the effectiveness of root cause analysis in post. *Information and Software Technology*, Volume 51, pp. 150-161.
- Bjørnson, F. O., Wang, A. I. & Arisholm, E., 2009. Improving the effectiveness of root cause analysis in post mortem analysis: A controlled experiment. *Information and Software Technology*, Volume 51, pp. 150-161.
- Dawson, J., 2024. *How do you conduct a value chain analysis to assess your business's activities and performance?*. [Online]
Available at: <https://www.linkedin.com/advice/3/how-do-you-conduct-value-chain-analysis-assess>
[Accessed 8 May 2024].
- Haas, M. R. et al., 2020. Applying Kotter's 8-Step Change Management Model to Residency Didactics. *Western Journal of Emergency Medicine*, 21(1), p. 65.
- Ismael, S., Santos, M. D. & Keiling, A. C., 2021. *The Intergration of DFMA and Reverse Engineering Applied to a Landing Gear Redesign*, Amazonas: UEA Manaus.
- James, J. A., Martilla, A. & John, C., 1977. Importance-Performance Analysis. *Journal of Marketing*, 41(1), pp. 77-79.
- Knowledge Sharing Centre, 2024. *Cost Price*. [Online]
Available at: <https://www.knowledgesharingcentre.com/manuproc/cost-price/>
[Accessed 8 May 2024].
- La Londe, J. B. M. J., 1994. Emerging Logistics Strategies: Blueprints for the Next Century. *International Journal of Physical Distribution & Logistics Management*, 24(7), p. 35.
- Leveson, N., 2011. *Engineering a safer world: Systems thinking applied to safety*, Massachusetts: MIT Press.
- Li, Q., Zeng, J., Han, Y. & Luo, X., 2019. Analysis on the Evolution Characteristics of China's Manufacturing Industry Structure——Based on the Perspective of Global Value Chain. *OP conference series. Materials Science and Engineering*, Issue 4, p. 42061.
- Lorenzo, D. & Jackson, L., 2008. *Root cause analysis handbook: A guide to efficient and effective incident investigation*.. 1 ed. s.l.:Rothstein Publishing..

Marhani, M. A., Jaapar, A., Bari, N. A. & Moha, . S., 2021. *Reducing Over-processing Construction Waste by Using Lean Construction Tools in The Malaysian Construction Industry*, s.l.: IOP Publishing Ltd .

Oh, H., 2001. Revisiting Importance Performance Analysis. *Tourism Management*, 22(6), pp. 617-627.

UBIsense, 2023. *The 7 Wastes of Lean Manufacturing*. [Online]
Available at: <https://ubisense.com/the-7-wastes-of-lean-manufacturing/>
[Accessed 22 May 2024].

Velling, A., 2021. *Design for Assembly*. [Online]
Available at: <https://fractory.com/design-for-assembly-dfa/>
[Accessed 27 May 2024].

Voehl, F., Harrington, J., Mignosa, C. & Charron, R., 2013. *The Lean Six Sigma Black Belt Handbook : Tools and Methods for Process Acceleration*. 1 ed. s.l.:Productivity Press.

Zamora, E., 2016. Value Chain Analysis: A Brief Review. *Asian Journal of Innovation and Policy* , 5(2), pp. 116-128.

Zhiguo , H., Wentao , L., Hadi, S. & Zhang, H., 2022. Integrated structural health monitoring in bridge engineering. *Automation in construction*, Volume 136, pp. 104-168.

Singh, B. and Sharma, S. (2009). Value stream mapping as a versatile tool for lean implementation: an indian case study of a manufacturing firm. *Measuring Business Excellence*, 13(3), 58-68.

Nasution, A., Siregar, I., Nasution, T., Syahputri, K., & Rizkya, I. (2018). Lean manufacturing applications in the manufacturing industry. *Matec Web of Conferences*, 220, 02005.

Singh, B. and Sharma, S. (2009). Value stream mapping as a versatile tool for lean implementation: an indian case study of a manufacturing firm. *Measuring Business Excellence*, 13(3), 58-68.