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Manufacturing Ergonomics Improvements in Distillery Industry Using Digital Tools

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Abstract

This paper presents the steps taken by distilleries to uphold years old traditions and how new design tools can streamlined the current manufacturing process/es. Different methods for bung removal are explored and how they are used today within warehouses and distilleries worldwide. The aim is to test new designs to replace the current tools used in distillery process to perform heavily manual tasks. Models of the current and new design are produced, and both are tested in a digital environment for ergonomics and time efficiency purposes.

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Keywords: Digital manufacturing system; Ergonomics; Design

1. Introduction

Scotland, a small country of 5.5 million people which is synonymous with rain, history, haggis, and The Loch Ness Monster but above all else whiskey. This 500-year-old practice can be linked back to its origins from winemaking methods which spread from monasteries in Europe. However, due to Scotland's lack of grapes around this time the monks substituted them for a grain mash to produce an early form of whiskey[1].

From the first recorded instance of the practice back in 1494, [1], the industry has developed into the major contributor to the food and beverage export sector of the Scottish economy with 130 distilleries raking in £4.7bn (74%) of £6.3bn in 2018 which was a 9.2% increase of 2017's £4.3bn, [2].This clearly thriving market has adhered to famous old traditions of whiskey distillation first implemented by its forefathers ranging from the equipment used, to the methodology used within its production. Some of these traditions have been streamlined and improved for modern times however, casks have been a fundamental aspect of the whiskey making process. These casks are typically American bourbon barrels or sherry barrels used to develop the flavour of the whiskey over time. These casks use a bung to lock the "water of life", [1] away for years, even decades to create a fine whiskey.

But what happens when it is time to retrieve this embodiment of Scottish history? Operators within the distillery use manual or mechanical methods to eject the bung from the cask. These methods have been in place for several years but unlike other operations within the whiskey distillery process they have not been adapted for modern times. Stresses within this removal impact on joints and small muscles potentially leading to repetitive strain injuries.

This paper focuses on the redesign of this old tool so that it is suitable for the standards of today. Designs focus on the ergonomics issue which affects operators the most when using the tool repeatedly and this is Repetitive Strain Injury (RSI). Ergonomic indices along with the use of digital tools were developed within a design methodology to compare the current tool against the redesign, an evaluation of the results is presented followed by conclusions.

Over the last 25 years, there has been a succession of small improvement steps in the brewing and distilling industries, resulting in lower labour, reduced consumption of raw

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materials, energy, and water, together with innovative solutions to effluent and by-product treatment. Process design and project implementation tools have benefited from powerful portable computers and ever more sophisticated software giving engineers the possibility of solutions, which could only be dreamed of at the beginning of the 1980s, together with reduced project timescale and overall engineering man-hours, [2]

Engineering solutions rely on the application of scientific knowledge, mathematics and innovation, of which the underlying principles have changed little during the last 25 years. Dramatic advances have been witnessed in digital and electronic technology and communications, coupled with computer capacity and internationally accepted standards that have had enormous influence on engineering outputs. Rapid developments in these areas continue to drive organizational and process changes, resulting in engineers executing their design and building tasks at a far more cost effective and efficient pace. Advances in computer aided design software (CAD) integrated with powerful database applications ensure the production of very high-quality engineering design information and construction drawings in a shorter time cycle.

This technology was emerging during the late 1970s, with specific applications in the aviation industry, but was restricted by computer hardware capacity. Following the introduction of digital tools and other similar products in the early 1990s, incremental improvements in software and hardware capacity have facilitated a migration from two-dimensional (2D) orthographic and isometric engineering drawings to complex three-dimensional (3D) models. Today 3D models can be readily accessed via free to view sample visualization software on most standard desktop or laptop computers. Client operations and project teams can visualise the layout and ergonomics of their future plant and equipment, which is often very large and complex in nature, before it is constructed and make valuable observations and contributions to engineering design, [3]. Detailed design analysis can also be completed using the 3D models without the expense of creating physical prototypes.

Several companies are adopting a more digital approach to business in response to the increasing levels of complexity of modern products and systems, the distributed engineering and manufacturing of these products, and the rising expectations from customers and business partners. Using digital innovation to improve business processes, supply chain efficiency, agility, and sustainability has become a necessity for competitiveness, [4]. Several software packages can now be integrated to 3D modelling systems offering increased accuracy and alternatives and, again, contributing to a much less expensive design cycle.

1.1. Removal of the Bung

The methods for removing the bung from the cask has been the same for many years. The bung of the cask lives within the bung hole. This bung has been in the cask for a minimum of 3 years if the liquid inside the cask is to be called a Scotch whiskey. It has endured a range of different temperatures and pressures as conveyed in the maturation section of the review. Operators within the distillery use 3 main methods to remove the bung from the cask:

- Flogging the Bung: the method involves applying a striking force several times to the barrel which, depending on the condition of the barrel, could cause damage to the barrel and to the operator performing the task.
- Mechanical Methods: This method destroys the bungs meaning they cannot be reused. Rather than using this method to achieve a sample it is typically used when the whiskey is drained from the cask as shown in source 18 when the cask has been transported to the warehouse to the machine. The operator in the video rotates the barrel assuring it is bunging side up and aligns the screw part of the machine to the centre of the cask. The machine is then activated, and the bung is split in 2 and removed by the operator. The task can be seen to be very repetitive and doesn't require a skilled operator to perform.
- Bung Extractor: This method, along with the flogging of the bung, is one of the oldest methods for bung removal. The method involves using a specialised tool design to be driven into the top of the bung and then twisted down until the screw has sufficiently been driven into the bung. Then an operator applies a sharp upward force (if bung id facing up) or a lateral force (if the bung is 90° from the upright position). The process only takes a few seconds to complete however one a continuous line the process can quickly become repetitive leading to injuries.

2. Design Methodology

Design thinking process integrated within digital tools is the methodology used for this work,[5] . This methodology offers a solution-based method to resolving problems. This allows for complex problems with little detail to be tackled effectively by understanding them with the primary focus the requirements of the human and building a framework around them. Then, brainstorming creative ideas, modelling and testing these ideas in a digital environment. This human centred design will allow the focus on the repetitive strain injuries and impact stresses to take priority in the design,[6].

Fig.1 shows the design methodology stages, described in the following sub-sections.

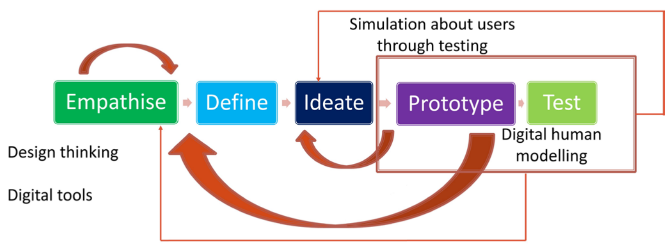


Fig. 1. Design Methodology.

2.1. Empathize

The first stage of the design thinking process is to obtain an empathic perspective of the task which is trying to be answered.

Professional opinions and expertise within the area were considered and analysed. Engaging and empathising with people using the product/tool allows for a deeper insight of the aspects which may be neglected by an outside designer. When using Design Thinking it allows the designer to set aside their own assumptions and perceptions of the world and step into the minds of a user and find their needs and how best to accommodate these within the design.

Three different types of removers were described by experts in the field. The main types are:

- The Bung Extractor which involves a corkscrew twisted into the bung and a jerking motion to remove the bung.
- Flogging the Bung which involves using a wooden mallet and striking either side of the bung to release it.
- Mechanical Method involving an overhead device lowered to the bung using switches that screws into the bung and pop it out.

These descriptions allowed for a focal point for the market research to be conducted around.

Fig 2. is a typical manual bung extractor. The design has the same corkscrew design as the mechanically operated design with the same physical aspect of flogging the bung. This tool allows for easy portability round the distillery and warehouse and allows for a faster extraction than flogging the bung. The design consists of two main parts, the pin, and the body. The body has a hammer-like design allowing for the tool to be used to put the bung back into the cask and allows for the operator to grip the tool well and allows for the upward force to be applied. The pin slides into the top of the body and can be locked into place when strike the top of the bung and then unlocked before the upward force is applied. This tool requires a great amount of force and if continuously used could lead to injury overtime.

Fig. 2. Bung removal tool.

2.2. Define

Throughout the Define stage of Design Thinking the information, which was obtained from the previous stage, the Empathize stage, is collated together. This is the stage where data analysis occurs, highlighting the core problems that have been identified from the previous stage. The stage allows for the designer to establish ideas, features and functions which can resolve the problem with the current design.

The human aspect of the tool is imperative to the design of the tool as the user's feedback and overall safety is key, [7, 8]. The tool must meet the regulations that have been outlined for safe use. The user will be using the tool constantly and the forces felt within the operation must be limited to help mitigate the stress/strain on the operator, [9].

From the design brief supplied the tool must also fully meet the European ATEX Directives delivering adaptability of use across all different sites, [10]. The tool is manually driven or contains its own power source for remote operation and the tool can be used by one hand so that one operator is enough to use the tool.

2.3. Ideate

The third stage of Design Thinking is where the designers start to generate ideas for the data which has previously been developed within the Empathize and Define stages of the process. By completing the previous stages, it allows the designers to adapt their designs to fit the user's issues which were brought up in the prior sections. There are many techniques found for ideation and these include brainstorming, brainwriting and worst idea possible. There is no limit to the number of ideas brought up within this stage however these ideas should solve the problem or supply the parts necessary to circumvent it.

During this stage preliminary sketches were constructed starting from bottle opener concept.
Hand sketches were constructed using Autodesk Sketchbook which allows for alterations to be made seamlessly to the sketches, [11]. Four sketches were ideated during this stage and considered for user's feedback. Fig 3. shows the sketches.

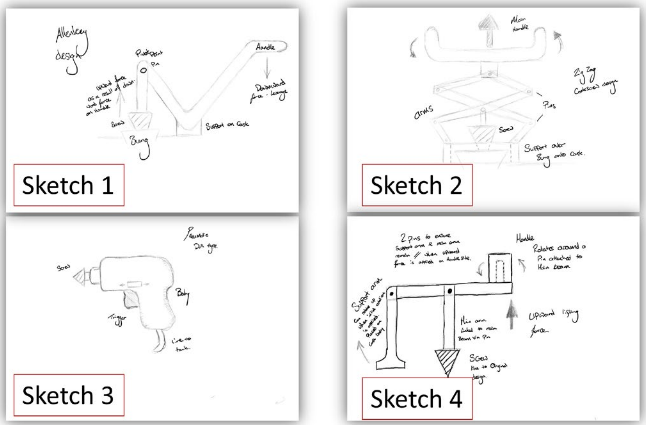


Fig. 3. Design sketches.

Sketch 1 shows level design which uses leverage to pry the bung from the hole. The design allows for a downward force to be applied to the tool and subsequently the bung which has been attached to the tool with a similar screw design as the original will pop out. The drawback of this design is the support on the cask. The support could slip when being used and along with the downward force could cause damage to the casks.

Sketch 2 is based off a zigzag bottle opener. The design is not very practical with too many moving parts. The weight of the design would also be greater than other designs due to all the different parts.

Sketch 3 is inspired by the mechanical methods of removing the bung and making them portable. It is a drill design which is used along with a power supply which the operator will use. The drawback of this design is the weight of the tool. The tool and the power supply would have to be worn by the operator during the shift and this could cause more effort to the operator due to the new added weight. Most distilleries and warehouses already have mechanical overheads which do not require the user to carry them.

Sketch 4 was the chosen design for the new tool. The design allows for the support leg to be made in line with the body allowing for the screw piece to be driven into the bung. The support is then placed onto the cask, or the hoop and the rounded shape of the support's face allows for the stresses to be spread across the face rather than at a point like if the face was not rounded. The handle is on a pin allowing the user to maintain a grip of the tool whilst rotating it. The handle is then pulled upward, and the support and the screw stay parallel to each other.

Models of the design currently being used within the industry and the new proposed design were constructed using Autodesk Inventor Pro 2021 as this package allowed for detailed 3D models to be created and allowed for high quality renders of the tools with the barrel in a realistic environment. The current tool was modelled using Fig. 2 in the empathise section. The measuring tape allowed for realistic scale, (20 mm) to be achieved for the tool as detailed technical drawings were not available. The models, which were created in digital environment are shown in Fig.4.

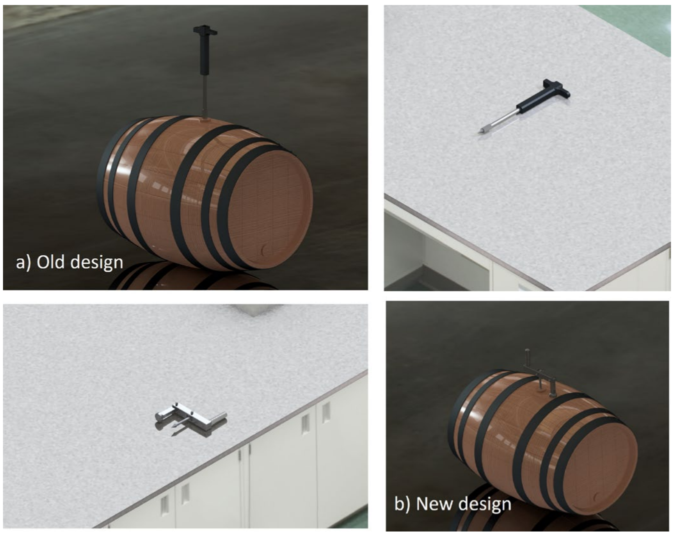


Fig. 4. (a) Bung removal traditional design; (b) bung removal new design.

2.4. Digital human modelling

Jack Human Modelling software 9.0 was used for the simulation of the tools within a realistic working environment. The software allowed for a computer-generated human to be implemented into a warehouse environment and the bung removal operation carried out with both sets of tools.

Both simulations started the same with the human at the bung and then prompted to grab the tool from the table a few feet away. The tools were then brought to the cask and placed onto the cask and screwed into the bung. An upward force of 200N was then applied to the tool simulating the forceful removal of the bung.

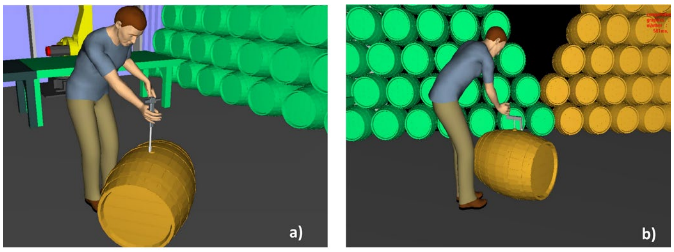


Fig. 5. (a) Current design posture analysis; (b) new design posture analysis.

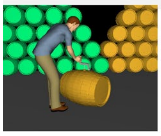
3. Ergonomics results

By simulating the operations in a virtual environment, the workers' postures were evaluated using the Posture Evaluation Index (PEI), developed and illustrated in [12–14]. The PEI integrates the results of the Low Back Compression Analysis (LBA),[15], the Ovako Working Posture Analysis (OWAS), [16], and the Rapid Upper Limb Assessment Analysis (RULA), [17], in a synthetic non-dimensional index able to evaluate the "quality" of a posture:

$$PEI = \frac{\text{LBA}}{3400} + \frac{\text{OWAS}}{3} + \frac{\text{RULA}}{5} \tag{1}$$

In Table 1 simulation results are reported.

Table 1. PEI Results.

Designs	LBA	OWAS	RULA	PEI
	2715	2	7	2.865
	417	2	6	1.989

When comparing the data from the different simulations developed in Jack Human Modelling the Lower Back Analysis of the original design is seen to be higher than the new design (2715>417). This results positively favour the new design showing that the user is greatly under the 3400N threshold set out by the software.

Ovako Working posture analysis for both designs featured showed a yellow rating of 2 on the evaluation. Both designs could lead to musculoskeletal issues for the user. It is not extreme in both designs however ways to limit these issues could be performing the operation with the cask elevated from the ground or having the operator kneeing or sitting to limit the amount of bending the back must endure whilst over the cask.

The Rapid Upper Limb Assessment for both designs showed negative results in both cases. The original design received a score or 7 the highest possible score on the scale indicating that action must be taken to correct these actions. The new design didn't score too well either with it ranking a 6 on the scale. This is slightly better than the current design but again action should be taken to correct this. A new posture would be suggested for the operations as it would be beneficial in both cases and especially in the new design as the force required wouldn't be the same in comparison to the current design as the support would be utilised more.

The comparison of the PEI indices shows that the current design is close to the upper limit for the index with the formula generating a value of 2.865, whereas the data for the new design generated a value of 1.989 for the index. These values show that the new design performs better in these ergonomic parameters compared to the current design.

Overall, the design is seen to perform better however changes could still be made to accurately represent the tools performance. More testing could've been performed with different percentiles, genders and regional variations being tested within the software. Prototyping was visualised however restrictions prohibited the chance for physical models to be made and tested in person. Restrictions also hindered the chance to meet and talk to the staff within many distilleries and warehouses and really gauge how they felt about the tool and what changes they would like to see within the design.

4. Conclusions and future works

The main aim of the paper has been fulfilled with the improvement of the bung removal operation in the distillation processes. This aim was achieved by developing a design methodology for improving the different methods used for removing the bung from the casks.

The methodology represents an innovative approach to design for thinking based on the integration between 3D parametric CAD systems, DMU tools, ergonomic tools and digital human models.

Preliminary sketches allowed for ideas to be visualised and helped lay the foundations for the final 3D model of the new design along with renders within a warehouse environment in Jack Human modelling and high-definition realistic renders in Autodesk Inventor Pro 2021. Data was produced using Jack Human Modelling to support the new design and compared it to the design currently being used within the industry today.

Future research will explore methods to improve the user interface with features to determine feasible operation routes of a product automatically. This will relieve the effort of the product designer largely.

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