



APPLYING LEAN MANUFACTURING TECHNIQUES

Advanced Manufacturing Systems

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ABSTRACT

This report aims to give a brief explanation of what lean manufacturing is and how it is used throughout the manufacturing industry. The types of waste that are associated with lean manufacturing are then discussed and applied to a real-life situation in relation to the delivery of parts trolleys to a station along an assembly line. The implementation of an alternative method of delivery that could potentially make the existing process leaner is then discussed. This concluded with the introduction of Autonomous Guided Vehicles being used for the process, along with the costs and drawbacks of implementing them.



TABLE OF CONTENTS

Abstract.....	1
Table of Figures.....	3
Introduction	4
Lean Manufacturing.....	4
The Service.....	6
Types of Waste	8
Waste within the service	10
Value from customer's perspective	13
Who is the customer?.....	13
Internal customer	13
External customer	13
Voice of the customer	13
How is the customer affected?.....	14
How the service can be made leaner	15
Challenges.....	16
Costs.....	16
Safety	17
Overcoming challenges.....	18
Cost savings.....	18
Maximum losses due to wastes	18
Estimated average losses due to wastes	18
Finding the right seller.....	19
Recycling batteries.....	20
Safety	21
Reducing risk of injury.....	21
Conclusion	22
References	23



TABLE OF FIGURES

Figure 1 - CTDA station locations and route (Red) and inventory location and route (Blue) on Dragon assembly	7
Figure 2 - CTDA trolley	7
Figure 3 - AGV cost comparison	16
Figure 4 - Myzer AGV specification	19
Figure 6 - CTDA trolley tow point	20
Figure 5 - Myzer Smart Mause 2000 All in One (Myzer, 2019)	20

INTRODUCTION

The manufacturing industry is becoming more and more competitive as time goes on. Due to this, manufacturing companies devote lots of time and money into developing ways to produce their product as fast and efficiently as possible without decreasing the overall quality of the product.

Ford Motor Company's (FMC) Bridgend Engine Plant (BEP) is a key example of a company that must maintain a successful and efficient process to ensure that engine production rates are high and able to meet deadlines on time. It is vital that BEP is able to achieve this as the plant is constantly competing with other Ford of Europe (FoE) and Ford of America (FoA) engine plants to secure contracts to start producing newly announced engines at a volume that accommodates the current workforce, securing their jobs for the foreseeable future.

This report focuses on highlighting and reducing the wastes associated with the assembly of the engines before they are shipped off to the customer. It will also include a possible solution to this along with any problems that it may encounter if implemented.

LEAN MANUFACTURING

Lean manufacturing is described by (Salemme, 2018) as a manufacturing technique that was introduced to essentially "do more with less" in an effort to cut the costs of manufacturing whilst still maintaining a high quality product. This approach focuses primarily on eliminating all forms of waste from a service to ensure that it is efficient as possible.

The idea of reducing the waste in any sort of working process stemmed from Henry Ford and he mentioned his views on it in his autobiography 'My Life and Work'. Ford famously compared the waste aspect of a service to a farmer, stating that only 5% of the energy expended by a farmer is put to good use. (Ford, 1922) mentions the way he feels a farmer goes about his business, stating "It is waste motion— waste effort— that makes farm prices high and profits low."

According to (Do, 2017), Taiichi Ohno, the Toyota Engineer and author of 'Toyota Production System' (TPS) developed the idea of lean manufacturing around the elimination of three deviations of the inefficient distribution of resources; Muda (waste), Mura (unevenness) and Muri (overburden). (Ohno, 1988) named 7 types of waste that should always be minimized to ensure an efficient manufacturing system. These are: Wait time, Over production, Over processing, Inventory, Transportation, Unnecessary movement and Defects. These wastes were developed by Toyota to help staff find the root cause of waste by analysing the flow of production or service implementation process (Chiarini, 2013). As the TPS grew and lean

manufacturing was developed, an 8th waste was added; Underutilising Staff Skills. Ohno openly stated that his work was greatly influenced by the book mentioned in the previous section; Henry Ford's 'My Life and Work'.

Many companies have adopted a lean approach to manufacturing since it was first developed by the TPS in the 1990s, including Ford Motor Company. In 1995 the 'Ford Production System' (FPS) was first developed to try and make Ford "the best in the world" in terms of manufacturing.

THE SERVICE

Bridgend Engine Plant (BEP) is a Ford Motor Company (FMC) engine production plant located in Bridgend and is currently producing the engines for both Ford and Jaguar Land Rover (JLR). These engines are machined and assembled within BEP before being shipped to vehicle assembly plants across the globe. Each of the production lines in the plant requires a substantial amount of materials and supplies daily to ensure that the engines produced meet the production demands of Ford and JLR.

Within BEP, the Material Planning and Logistics (MP&L) department deal with the management of materials in a supply chain function around the plant. This ensures that each station located on the Sigma and AJ production lines have the correct level of parts to enable employees to build engines at a required rate.

The Dragon assembly line in BEP differs from the Sigma and AJ assembly lines, as it does not rely on the MP&L department to supply each station on the assembly line with stock throughout the day. This is due to a newly implemented system involving kit trays that are attached to each engine platen with all the parts needed for that engine in the assembly process. However, some parts are not included in this kit tray and are stored on portable trolleys around the line. These trolleys are regularly filled/emptied by a member of the assembly team throughout the shift.

An example of parts that are not included in the kit trays are the Cold Test Drive Adapters (CTDA). These are fitted mid-way through the assembly of an engine, allowing it to be tested to ensure that all the components are working up to this point in the assembly. The CTDA is removed four stations later (90m between fit and remove stations) and the engine progresses to final assembly. These stations are located at different points in the line (See Figure 1). The adapters are then placed on to a trolley that is then used by the team leader to transfer them back to the fitting station so they can be reused.

When the Dragon assembly line was first installed, 400 CTDAs were ordered to ensure that there were plenty of spares so that the line was never short of adapters. This allowed for regular scheduled maintenance system (SMS) on the adapters to make sure they were free of any damage or defects and would not damage the engines in any way (e.g. a broken thread could damage the engine thread). However, due to an unforeseen drop in the demand for engines, the number of adapters required for the line also dropped. This meant that they would now have to be kept in inventory (See Figure 1). A weekly rotary scheme was put in place to split the CTDA stock, ensuring that all adapters were being used instead of one half being used excessively while the other half wastes away in inventory.

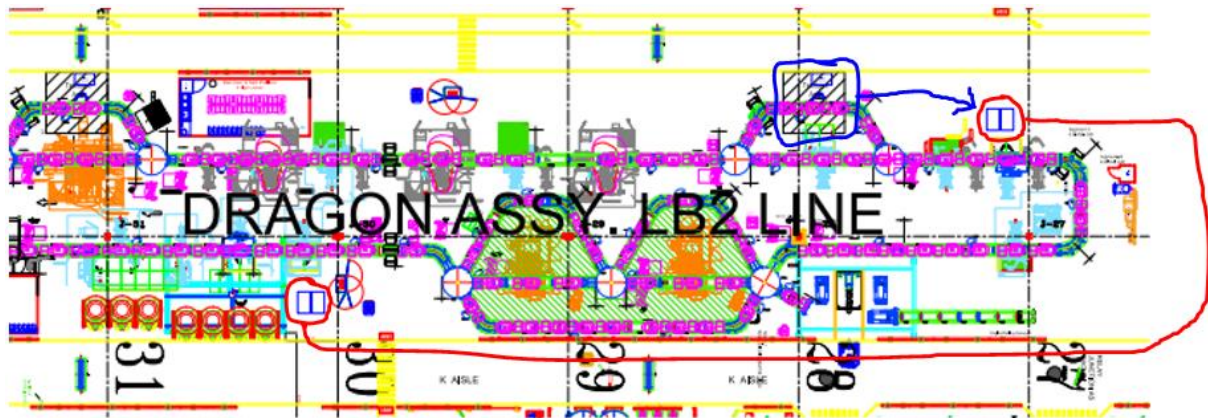


Figure 1 - CTDA station locations and route (Red) and inventory location and route (Blue) on Dragon assembly



Figure 2 - CTDA trolley

TYPES OF WASTE

Transportation

Transportation waste, according to (Gay, 2016), is the waste produced by excessively transporting goods via a poorly planned route. In some cases, the route taken during transportation is efficient but poor plant design has an effect. This can enhance other forms of waste such as waiting or motion, as well as effecting the overall cost of the process in the form of fuel, energy, wear and tear of vehicles under a needlessly heavy load.

Inventory

This type of waste is often related to poor planning when materials/stock is being ordered and consists of excess stock that is not required by the manufacturer at that current time. Excess inventory is a problem for manufacturers as it will drive the overall cost of production up as the cost to hold and transport goods will increase (Skhmot, 2017). Inventory waste should not be neglected as it often triggers other forms of waste e.g. the longer materials are kept in inventory; the more susceptible they are to sustaining damage.

Motion

Motion waste is defined as the waste produced by any physical movement such as reaching, walking or bending carried out by a person working as part of a manufacturing process that is not necessary to the task in hand. This type of waste should not be overlooked as it will increase the time taken for the process to be completed, which would increase the cost (Gay, 2016).

Waiting

This type of waste occurs when work being carried out is not consistent throughout the different operations within a process. (Gay, 2016) states that waiting is often the outcome of a poorly designed system and can have knock on effects that may increase the waste production in other categories. For example, if wait times are substantial then production may be rushed to meet deadlines, resulting in a poorer standard of a product.

Over production

The production of parts that exceeds the demand or the customer requirements. This type of waste has a knock-on effect to other types of waste such as inventory, transport, motion and possibly defects as the unused stock will be stored in inventory. This uses time, transportation resources and costs money to store, which also increases the risk of parts being damaged whilst in inventory. Due to this, it is stated by (Ohno, 1988) that overproduction is deemed as the biggest problem that industries must put up with in terms of lean manufacturing.

Over processing

Any additional processing steps carried out on a product are often seen as wasteful as in most cases, they do not add value to the product. Manufacturers often make the mistake of over processing a part with the customer in mind, however in reality the extra work is often seen as wasteful or unnecessary (Skhmot, 2017). An example of this is a manufacturer working to a small tolerance that is not essential to the customer's needs, therefore adding unnecessary time, effort and resources (machine tool life) to the overall process.

Defects

This type of waste occurs when a product does not meet the appropriate quality standards of the customer due to a defect. This type of waste is common in manufacturing as it can occur at any point in the process of a part e.g. from a machine error during machining due to tooling fatigue/failure or accidental damage during inventory or transportation (Gay, 2016). If a defect during the machining stage of a part is noticed then in some cases the part may be recovered with the use of excess machining, however if the part is not recoverable then it must be scrapped.

Utilising Staff

In some cases, an employee's skill level exceeds the skills required for their job role. It would be beneficial to both the employee and employer if the employee's skills were being utilised, however in most cases the employee will just simply follow orders and not implement any additional skills or knowledge that they possess (GoLeanSixSigma, 2017).

WASTE WITHIN THE SERVICE

The wastes produced by the current process in which the cold test drive adapter trolleys and stock are changed over were discussed and analysed in an interview with David Canfield, Senior Industrial Engineer for the Dragon assembly line on 04/07/19.

Transportation

The Dragon assembly production line is poorly designed in terms of transport waste. If the line was designed in such a way that the CTDA fit station and remove station were within approx. 5m of each other, the return of the CTDA's could be carried out with the help of a roller track. However, this was not considered during the process mapping of the Dragon assembly line and cannot be altered; therefore, the transportation waste cannot be reduced.

Inventory

Projected engine quantities are specified in advance for each shift, allowing Dragon marketplace to prepare the kit trays for each engine. It also gives the team leader an idea of how many CTDA need to be in cycle. The current procedure is the number of engines required + 25. This number of adapters is then added to the adapter trolley and the remained are left in the maintenance area, essentially in inventory. The adapters in inventory and the adapters being used are rotated on a weekly basis to ensure that any damage or defects do not occur from this type of waste.

Motion

The largest form of waste in this service that triggers other forms of waste is due to the unnecessary movement carried out by an employee during the CTDA trolley changeover.

The time taken for an operator or team leader to carry out this task is approx. 6 minutes to walk 95m from the removal point to the fixing point to empty the CTDA trolley, then take the empty trolley back, with an additional minute or so in-between spent positioning the full trolley and retrieving an empty trolley from the designated zones. This task is carried out approximately once every two hours, totalling 4 times in a standard 8-hour shift. This means that the person carrying out the task travels 760m per shift.

There is also motion waste involved in the changing over of stock from inventory. This waste is less frequent however as that changeover only occurs once a week as opposed to four times per shift.

Waiting

The waiting waste for this process is triggered by the unnecessary movement carried out by the person tasked with the job of changing over the parts trolleys. The motion waste mentioned

in the previous section adds up to roughly 30 minutes of time spent by the operator being somewhat wasted by pushing a trolley. In some cases, the person assigned to the task of changing the trolleys is has taken too long, then both trolleys are full. This means that when the trolley is in the process of being changed over, the line will be on stop as operators will have to wait for the CTDA trolley to be returned before continuing their job of removing the adapters. This is a common occurrence as sometimes employees fail to balance their workload correctly and can result in 15-30 minutes of downtime.

Waiting waste can also occur in cases when the team leader is assigned to the task of replacing the stock trolleys, as they may be required to attend things such as morning meetings. In this event, the stock change task is often put on hold until they have finished in the meeting as assembly workers are not likely to go out of their way to get the line back up and running. This will influence the waiting waste as the process will stop production for a short time. This increased cycle time can add up and effect production/JPH, which in turn could mean that production rates are not met for that day

Over-production

As the CTDA's were ordered in a specific quantity in one go, this type of waste is not included in the current process.

Over-processing

This type of waste can occur if CTDA's are deemed to have defects. However, parts that are damaged are sent to the toolroom for them to fix, so any processing waste included in the repair would be passed on to them and not affect this process.

Defects

This type of waste can occur if parts are kept in inventory for too long or if operators are careless when fixing and removing the CTDA's from engines. Regular SMS checks are carried out to ensure that any defects are picked up early so that they do not affect production. However, if operators are not available to rotate the current stock with the inventory because they are tied up with other jobs, the time between SMS checks will increase.

Currently this process of swapping the CTDA over is being controlled manually. The problem with this is that issues have occurred in the past, usually when the team leader has been off or in a meeting, in which this process is not followed, resulting in maintenance not being carried out as required. If the stock swap is missed, it is likely that the changeover will not occur until the next scheduled changeover the following week, meaning that the stock could go two weeks without being changed over. If this occurs, any damage or defects to a CTDA may not be picked up until the next changeover and the risk of damaging an engine is increased.

Underutilised Staff

The employee assigned to changing trolleys over is being wasted as that task does not require any skill to carry out. Each operator on the line has been put through a training program to ensure that they are able to assemble an engine in the correct manner, ensuring that all quality procedures are followed along the way. If assigned to the task of pushing a trolley around, the skill set of that employee is not being used to the best of its ability.

VALUE FROM CUSTOMER'S PERSPECTIVE

WHO IS THE CUSTOMER?

The customers who are on the receiving end of the service mentioned in this report are both internal and external.

Internal customer

There are two internal customers on the receiving end of this process. The first internal customer is the CTDA fixing point. This customer requires a consistent supply of CTDA and a weekly inventory changeover. The second internal customer is engine buyoff. Every engine produced by the assembly line is taken by this customer and they prepare it for delivery

External customer

The external customer that the Dragon Assembly Line supplies are the Ford vehicle assembly plants located in Cologne and Saarlouis. These plants rely on the assembly line to produce and supply a high volume of good quality engines to contribute to high quality engine performance.

VOICE OF THE CUSTOMER

Voice of the Customer (VoC) is described by (iSixSigma, 2019) as a term used to describe the feedback of the customer in relation to their experiences and expectations for the products or service that is being offered. In relation to customers of BEP, quality and quantity are the most important things they look for in the service when they order engines from the plant. This is due to the high standards of production that have been set by FMC plants globally over many years.

HOW IS THE CUSTOMER AFFECTED?

Information in the following section of the report was taken from an interview with the Senior Dragon Industrial Engineer, David Canfield on 04/07/19.

The line has a station cycle time of 124 seconds, which is a capacity of 29 engines per hour at 100% uptime. The target uptime for the line is 90% (Global target for FMC assembly lines), which allows a cushion of 10% downtime in the event of any breakdowns. Running the line at 90% equates to a production rate of 26 engines per hour. This gives a shift capacity of 179 engines per shift on an estimated 6.875hrs production carried out on a shift.

If transporting the trolley must be carried out by the line side operator, as previously mentioned in the wastes section, they would have travelled a total of 760m in a time of approximately 30 minutes. This could then drop production time from the standard of 6.875hrs to 6.375hrs, now equating to the line producing 166 engines per shift, which is essentially a loss of 13 engines. This does not mean that 13 engines are lost every shift due to this trolley changeover as some days the job is done when the line is down due to a breakdown. However, if there are no breakdowns then this figure will influence the production rate of the line that shift. If left to accumulate over time, what seemed to be a small problem could now develop into a much larger problem that may result in the line underperforming to the customer's needs.

All the customers that are involved with the service are chain linked as if one of the internal customers is not satisfied, it will have a knock-on effect that will eventually affect the external customer; who is the most important. If the CTDA fixing and removal stations are causing delays in the process, then the production rate of the line will decrease, influencing the number of engines that Buyoff are given to pack and store before delivery. This will therefore slow Buyoff down and could cause delays in the delivery of engines from BEP to other engine plants.

HOW THE SERVICE CAN BE MADE LEANER

Due to the somewhat poor planning that has gone into the Dragon assembly line layout, transport wastes cannot really be reduced. It can however be taken off assembly workers hands.

An alternative service that could potentially be implemented into the current process is that of Autonomous Guided Vehicles (AVG). This type of vehicle follows a predetermined pathway with the use of various motion sensors and cameras to complete a process or series of tasks assigned to it via integrated software (Fazlollahtabar & Saidi-Mehrabad, 2015).

If utilised properly, the majority, if not all the types of wastes mentioned in the previous section of the report that have a negative effect on the process could be greatly reduced. The routes currently taken by employees can be mapped out using either magnetic tape or aerial cameras that map out a pathway for the AGV to follow.

According to (Benevides, 2018), one of the main benefits of AGVs is the fact that they are autonomous, meaning that they do not require comfort, lunch or toilet breaks and are ideal for carrying out a repetitive function at the push of a button, or with the use of a timer. Utilising this feature would allow for a consistent CTDA stock changeover with the inventory, ensuring that parts are cycled consistently and do not miss any SMS checks. A pushbutton call system can be integrated into the AGV software so that if a parts trolley is full/empty and requires changing, the operator can push a button and the AGV will come and perform the task, causing minimum disruption to production. This would not have a huge effect on reducing the defect and inventory waste, but it will ensure that the stock is being cycled on a weekly basis to help reduce the chance of any problems developing.

If a stock trolley is attached to an AGV instead of being pushed by a BEP employee, then nearly all the responsibilities of that job are taken off the employee's hands and transferred to the AGV. This means that the use of an AGV would massively reduce the motion waste related to this task from the 760m travelled by the operator per shift to around 20m. The motion waste would not be completely eliminated as the trolleys would have to be unloaded at a safe distance from any stations to avoid collisions and injuries, meaning the operator in the CTDA fixing station would still have to walk a short distance to retrieve the trolley. This takes some of the work load off the team leader/operators, allowing them to utilise their time more efficiently on tasks that may help speed up production and not waste it on the robotic task of moving trolleys from one point to another. This also ensures that they are being utilised for the job that they are being paid sums of around £45,000 per year to do instead of repetitive tasks that require no skill.

CHALLENGES

COSTS

The main problem associated with implementing AGVs into this service is that they might not be deemed necessary by management. Considering that the waste being produced by the service seems very manageable from the outside looking in, it is very unlikely that the costs listed in Figure 3 would be justifiable.

	KIVNON K11 MOUSE	CLEM CM3000	ASTI Bidibot
AGV			
Length (mm)	2010	2266	2000
Width (mm)	500	420	500
Height (mm)	333	250	230
Payload			
Payload (kg)	3000	3000	2000
Speed			
Max speed (m/s)	0.75	0.66	0.7
Batteries			
Battery	AGM	Lithium Ion	Lithium Ion
Charging Time (h)	1	1	1
Working time (h)	8	8	8
Communication			
Type	Radio	WiFi	Radio + WiFi
Guidance			
Type	Magnetic	Magnetic	Magnetic
Scanner	Sick	Sick	Sick
Maintenance / year			
Service	National	Local	National
OEM:	SEAT, BENTLEY, JAGUAR, MERCEDES, VOLKSWAGEN, NISSAN, OPEL, ABB, RENAULT	FAURECIA, FORD, RENAULT, SEAT	PSA, OPEL, VAUXHALL, MERCEDES, SEAT, VOLKSWAGEN, RENAULT, NISSAN, TOYOTA, FIAT, IVECO, RENAULT TRUCKS, FAURECIA
Cost			
Approx. Price	£22,230.00	£20,886.50	£20,681.00

Figure 3 - AGV cost comparison

SAFETY

The thought of an unmanned vehicle travelling around the vicinity of a production line located inside one of the largest factories in the UK does raise concerns in terms of health and safety. The idea of these vehicles could be intimidating for the workforce as there is no interaction with an AGV as there is with a person driving to signal that a person crossing the road has been noticed. This is a common obstacle that companies face when attempting to integrate AGVs into the manufacturing process (Moreton, 2019).

OVERCOMING CHALLENGES

COST SAVINGS

Initially, the main issue with implementing AGVs into BEP was the cost of the vehicle. However, after obtaining the typical downtime figures and instances in the (Canfield, 2019) interview in the 'Value from the customer's perspective' section of this report. When calculating those figures with the cost of a Dragon engine (Thomas, 2019), the following assumptions could be made to justify the implementation of an AGV to reduce the waste within the surface.

Maximum losses due to wastes

The following calculation is in the event of a maximum 13 engines being lost every shift throughout the 5DC pattern due to the CTDA trolley changeover wastes and the effect it has on employees being fully utilised.

$$13 \text{ (Engines lost per shift)} \times £1413.75 \text{ (Unit cost)} = £18,378.35$$

$$£18,378.35 \times 15 \text{ (Shifts per week)} = £275,675.25$$

Estimated average losses due to wastes

The following calculation is in the event of a realistic estimation of 3 engines being lost every shift throughout the 5DC pattern due to the CTDA trolley changeover wastes and the effect it has on employees being fully utilised.

$$3 \text{ (engines lost)} \times £1413.75 \text{ (Unit cost)} = £4,241.25$$

$$£4,241.25 \times 15 \text{ (Shifts per week)} = £63,618.75$$

Finding the right seller

BEP now has its own department that is assigned to trialling and implementing new technologies that may have a modern-day influence on improving manufacturing within the plant: Emerging Technologies (ET). When the engineers in this department had been comparing the costs of available AGVs that are used in other manufacturing plants across Europe, they came across a developing AGV company based in Poland called Myzer. This company offered a smaller, faster and cheaper alternative of what the main AGV companies had to offer called the Smart Mause 2000 (Moreton, 2019). This AGV had a smaller payload than the other AGVs in the field but that factor is not essential for the required service, making it more efficient than the other options. Coincidentally, the AGVs are also almost compatible with the current CTDA trolleys as they already have a tow point that was originally in place in case the trolleys were to be attached to the MP&L tugs (See Figure 6). Small modifications may be required on Myzers part to ensure full compatibility.

Myzer Smart Mause 2000	
AGV	
Length (mm)	1200
Width (mm)	400
Height (mm)	250
Payload	
Payload (kg)	1600
Speed	
Max speed (m/s)	1.33
Batteries	
Battery	Lithium Ion
Charging Time (h)	1
Working time (h)	8
Communication	
Type	Radio + WiFi
Guidance	
Type	Magnetic + Visual
Scanner	Sick
Maintenance / year	
Service	National
Cost	
Approx. Price	£12,500.00

Figure 4 - Myzer AGV specification

Recycling batteries

The engineers in ET were impressed with what Myzer were offering and met with one of their representatives and in doing so discovered that the Myzer AGVs operate using 48V MHEV Type C Lithium Ion batteries. These are the same batteries that are being used in the Ford Focus Electrical Hybrid car and the appropriate disposal of these engine batteries is coincidentally another project that ET engineers have been working on. The use of these batteries in the AGV is possible and if BEP were to purchase a Smart Mause 2000 and provide the battery, a total of £4000 will be saved on the cost of the vehicle, bringing the cost of the AGV to £8500.



Figure 6 - Myzer Smart Mause 2000 All in One (Myzer, 2019)



Figure 5 - CTDA trolley tow point

Safety

AGVs are equipped with various safety features to avoid any collisions when in motion. According to (Bell, et al., 2016), these features will differ depending on the type of AGV that is being used but often include multiple features including motion sensors, cameras and laser scanners. AGVs have been around for many years, meaning that these features have been trialled and tested thoroughly over the years to prevent collisions and accidents at all costs. The Myzer Smart Mouse consists of a visual guiding system that is mapped out with the use of aerial cameras that can be installed anywhere, that is used along with multiple motion sensors to map out a safe route with no collisions. Other safety features can be implemented around BEP to further enhance the safety aspect surrounding the use of the AGV. These include traffic lights, reverse sirens and slowing down at road crossings.

Reducing risk of injury

Although ergonomically trialled and tested, the trolleys will undergo wear and tear during their lifetime, meaning that they could become harder to push over time. This could result in strain related injuries to employees that could result in an injury claim being filed against BEP, accumulating negative press and excess costs. The use of AGVs will eliminate the risk of any injuries sustained to employees assigned to push the trolleys, therefore eliminating the addition cost of an injury pay out.

CONCLUSION

The current system that is in place on the Dragon assembly line to return and rotate cold test drive adapters has many holes in it that lead to several of the 8 wastes mentioned in this report becoming a problem. The main wastes included in the current process were mainly transportation, motion, waiting and underutilising staff, with inventory and defects playing a minor part.

Five of the six wastes that are causing problems in the system could be reduced and potentially solved with the introduction of autonomous guided vehicles, with transportation being the exception. If implemented successfully for this service, this use of the AGV could be used as a steppingstone for them being used in other services throughout BEP in which lean manufacturing waste is a concern. The wastes looked at in this report were not considered to be a problem by certain areas of management within BEP, however this was not the case once they were investigated properly as this report has shown.

The main issue surrounding the implementation of AGVs was whether they would be worth the investment. I feel that this report has answered that question as the Myzer AGV that costs £8500 would massively reduce the weekly downtime costs of £63,618.75. I also feel that collaborating with the ongoing battery project would be a huge benefit for BEP.

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