

Designing a tool delivery system utilising an Automated Guided
Vehicle to reduce the wastes present with an existing process and
increase productivity

By

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I. STATEMENT OF AUTHENTICITY

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

Signed: Joshua Rhys Evans

Date: 14/06/20

II. ACKNOWLEDGEMENTS

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Finally, I would like to thank my project supervisor, Andrew Thorn for his help and guidance throughout the duration of the project.

III. ABSTRACT

When production demands were not adhered to across consecutive shifts, a meeting was held involving supervisors and team leaders of Ford Motor Company's Dragon Machining line in Bridgend Engine Plant to find out why. The source of this problem was anticipated to be in relation to the wastes present with an existing process regarding tool changes, which was implemented when Dragon first arrived in Bridgend in 2017.

The project focuses on building a completely new and efficient process to aid with the delivery of tools, from the Dragon machining tool crib, to various machines located around the area. To aid with this goal, a literature review was carried out in order to provide the author with the relevant knowledge on the subject, as well as on the tools and methodologies that can be utilised accordingly to reduce and eliminate wastes.

Data was then collected and analysed to provide evidence of the problem in terms of the cost and quantity of waste. The results of this analysis influenced the decision to investigate the idea of using an Automated Guided Vehicle (AGV) to deliver tools. The available technology was then explored in-depth to provide the most suitable candidate that could be used as part of the new process within the plant.

When a suitable candidate that fitted a set criterion was selected, the information gathered on that specific AGV was used to create a conceptual design process. This process was then subjected to further development and planning to reduce any potential failure modes using the relevant engineering tools and methodologies. A final design was then constructed for cost and payback analysis to be carried out, highlighting the total cost savings of the project and the impact it will have.

The findings of this report will not be immediately implemented due to the closure announcement of Bridgend Engine Plant; however, the appropriate steps have been taken to ensure that the project is eventually implemented correctly. These include full-scale development and mistake proofing a detailed design as well as the management of change strategy that should be followed.

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VII. ACRONYMS AND ABBREVIATIONS

AGV – Automated Guided Vehicle

BEP – Bridgend Engine Plant

BOP – Bill of Process

CMM – Coordinate Measuring Machine

CNC – Computer Numerical Controlled

DFMEA – Design Failure Mode Effect Analysis

ET – Emerging Technology

FMC – Ford Motor Company

FMEA – Failure Mode Effect Analysis

H&S – Health and Safety

HSE – Health and Safety Executive

LGV – Laser Guided Vehicle

MP&L – Materials, Planning and Logistics

OR – Operational Requirements

OP – Operation

SLAM – Simultaneous Localisation and Mapping

TCF – Tool Change Frequency

1.0 INTRODUCTION

1.1 INTRODUCTION TO THE PROBLEM

Employee utilisation affects the efficiency in which workers perform, requiring them to balance workload effectively to certify that tasks are completed on time. This is especially required within industry, as there will often be specific deadlines that must be adhered to. Management within Ford Motor Company (FMC) expect the target up time for each line to be in the vicinity of 90%. If this target cannot be achieved, then questions will be asked of supervisors and team leaders as to why as Ford operate under a lean manufacturing approach. FMC employees are expected to make use of their time accordingly to ensure that production does not fall below the 90% target. If employees are not able to utilise their time accordingly due to circumstances that are out of their control, management will intervene to assess the situation and attempt to provide an acceptable solution.

The demand for a solution to this problem was requested by senior management in BEP, hence allowing this project to be undertaken. The goal is to investigate the current issues regarding operator utilisation on the Dragon machining line and providing a feasible and cost-effective solution.

1.2 BRIDGEND ENGINE PLANT

Ford Motor Company's Bridgend Engine Plant (BEP) consists of eight fully operational machining lines that contribute to the production of Ford and Jaguar Land Rover engines on a global scale. These lines use various types of Computer Numerical Control (CNC) machines to machine the raw castings of engine components within a specific tolerance to provide the highest quality engines to the customer.

Three of the eight machining lines situated in BEP come under Dragon Machining and contribute to the machining of the Dragon head, block and crankshaft. Fully machined parts are then checked and stocked before being sent to the Dragon Assembly line to build fully functioning Dragon 1.5L GTDI petrol engines. The original plan for the Dragon engine was to be produced in three Ford plants located in Mexico, China and Wales, but this changed when Ford announced the closure of the Bridgend site for September 2020. This led to Bridgend being the sole manufacturer of the Dragon engine for the start-up period with management assigned the responsibility of reporting any problems faced with the implementation and documenting how they were solved. This was key during the start-up as all three of the plants producing Dragon have to abide by Ford's Bill of Process (BOP) system, meaning that each of the lines has to remain identical in terms of laid down procedures, layouts and processes, making Bridgend an essential asset to ensure the success of the Dragon project.

1.3 PROJECT TEAM

This report will investigate the costs of the wastes present with the current service to highlight the problem for upper management, prompting them to fund a solution. This report will investigate the newest innovative technologies that are being introduced to the industry as opposed to simply adding extra labour to the area, thus increasing the wage bill for that department. To achieve this, a Project team was required, consisting of individuals specialising in different areas to contribute to the completion of the project to the best possible standard.

The Project Champion, being the author of this report, will have the most active role of the project, conducting the research and development aspects of the project, as well as exploring the relevant technologies that are available on the market today which could be brought into BEP. Phil Moreton, the Senior Emerging Technologies Engineer, will be contributing to the project by utilising both technology and business contacts that have been accrued during his time in the Emerging Technology department to help work towards the best solution possible. Dragon Machining manager Richard Whitelock will be overseeing the project to ensure that any timeframes and FMC guidelines are adhered to throughout the duration of the project. Machining Supervisor Gary Williams will play a similar role, focussing more closely on the machining line, aiding the team with any information and contacts regarding the Head and Block lines. Gary's role will also involve permitting time for the Project Champion to discuss the project with various employees throughout the area whose contributions may be essential to the project, such as engineers, team leaders, operators and tool crib employees.

The Project Champion will be carrying out the most part of the project while the rest of the team will be essentially be supervising their areas of expertise throughout the project. The management side of the team will be essential assets for the end goal, collectively reviewing the findings put forth by the project champion before advancing to the next stage.

1.4 TIMING PLAN

The use of a Gantt Chart is essential for determining the start and end dates of tasks to ensure that they are completed by the desired date. Following these guidelines will ensure that the project does not overrun deadlines agreed upon with management and project tutors.

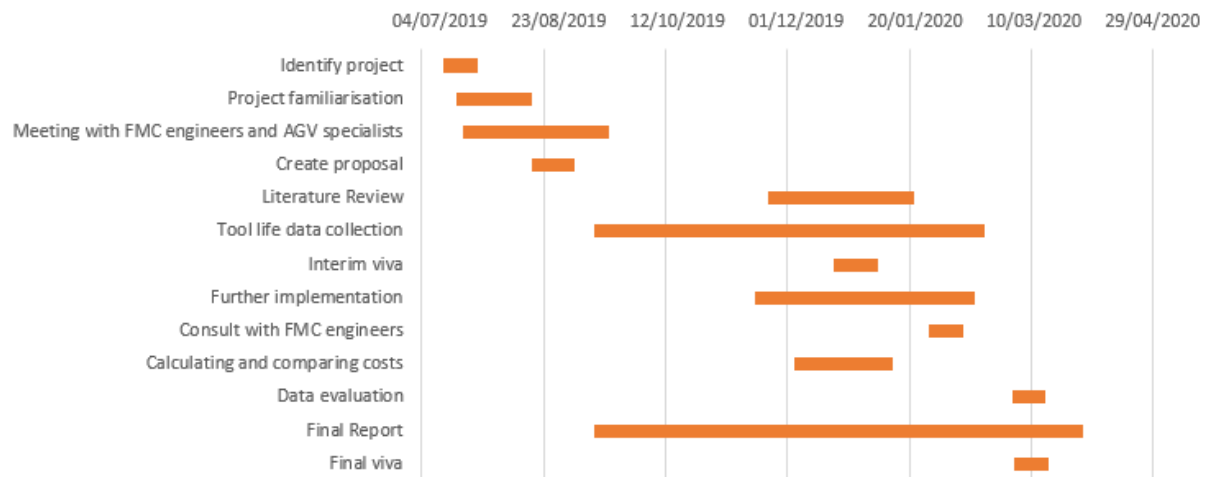


Figure 1 – Project Gantt Chart

2.0 DEFINE: EVIDENCE OF THE PROBLEM

2.1 FINDING THE SOURCE

On machining lines, the Jobs per hour (JPH) scores are not as critical as on assembly as parts are often batch built to ensure a buffer of parts for the assembly line to use. However, the scores do reflect on the output of the line and will raise questions towards higher management who will want answers from foremen as to why the line is not performing to its full working potential.

When JPH values on the Dragon Head & Block machining lines were not consistently adhered to throughout multiple shifts (see figures 2 and 3), a meeting was called to address the concern. The meeting was conducted by one of the foremen on Dragon machining Gary Williams, (2019) and involved questioning team leaders in regards to any problems that may have been encountered with tooling, downtime and other issues that may effect quality.

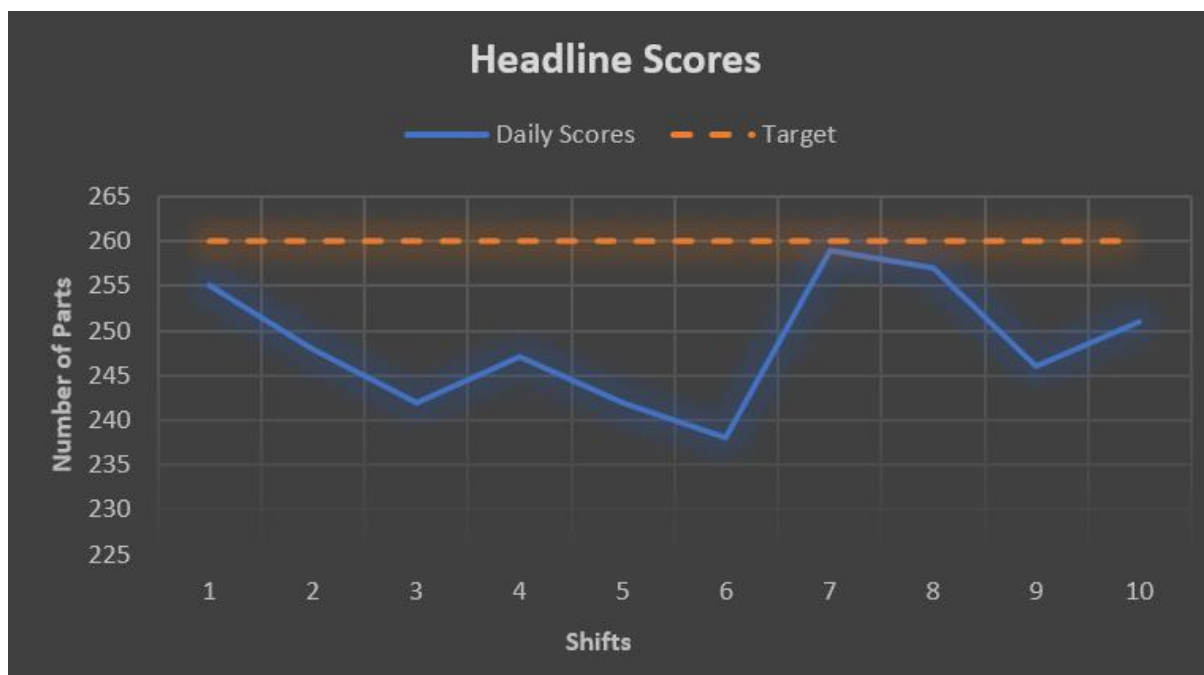


Figure 2 – Headline Shift Scores

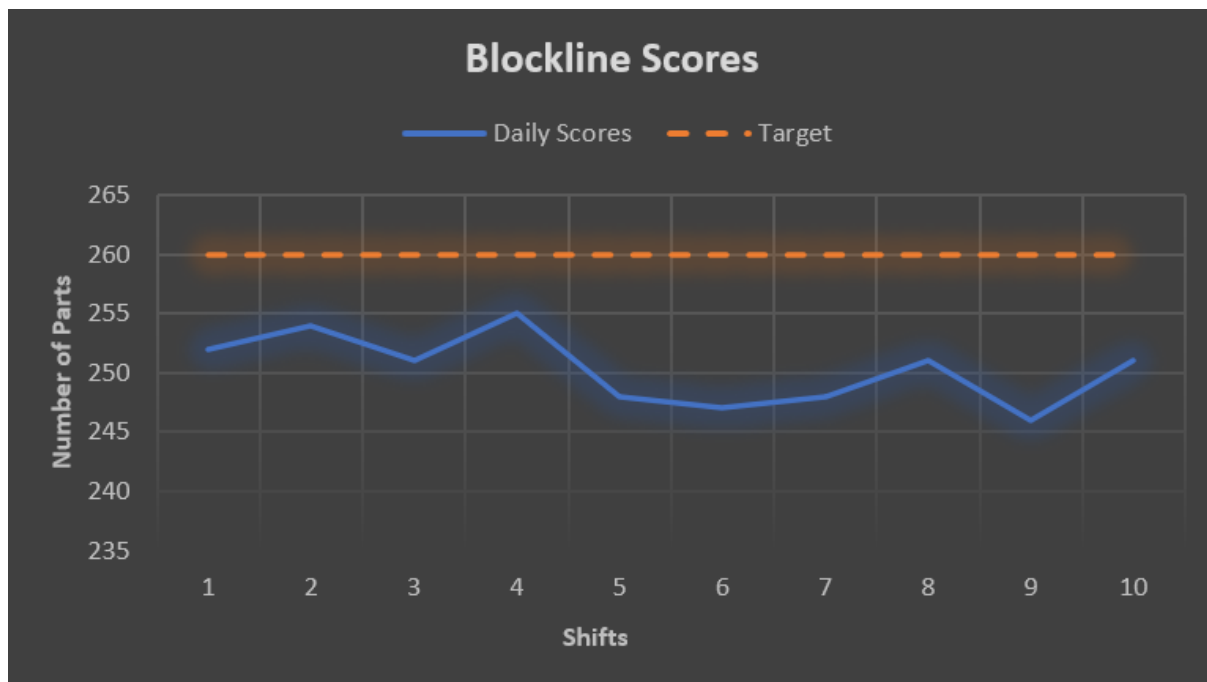


Figure 3 - Blockline Shift Scores

Cresswell, (2019) explained that after congregating with the operators who run the machines, there were multiple mentions of the duration of tool changes which involve the operator walking to and from the tool crib situated at the top end of the machining line. Cresswell, (2019) then went on to explain that some of the operators were not finding the time to implement regular tasks in regards to maintaining the tidiness of their assigned areas or machines, with some concerned that this may correlate to the increased number of breakdowns that were experienced in recent shifts.

2.2 CURRENT PROCESS

2.2.1 Continuity between plants

The current tool change process is a newly implemented system as it was introduced to Bridgend Engine Plant along with the most recently installed Dragon Head & Block Machining line. The Dragon engine variant is set to be produced in three Ford Engine Plants located in Mexico, China and Wales. These chosen plants are required to abide by a bill of process (BOP) system so that each production line is identical in terms of line layout, manufacturing processes and laid down procedures.

“The idea being that these lines are inseparable, so much that a Ford employee that has been trained to work on Dragon machining could operate at any of the three plants, with the only distinguishing factor being the language spoken” - Whitelock, (2019).

As the Dragon engine was first set up in BEP, management in the plant have been instructed to identify and rectify if possible, any ‘teething problems’ that may be present once the line is in full operation.

2.2.2 Tool change process

The tool change process that is currently in place on the Dragon machining lines in BEP differs from the other delivery methods used in the plant as Dragon has a tool crib located next to the machining lines. Due to the proximity of the tool crib to the line, a decision was made to aid with cost savings by utilising operators to retrieve and return tools, thus reducing the labour required by one man per shift on a four shift pattern. However, given the concerns that were raised in the meeting discussed in section 2.1, there may be flaws present with the current process:

Dragon Machining Tool Change Process

- Tool crib employees or 'Tool setters' are notified of any upcoming tool changes via monitoring software integrated with each machine on the line, allowing them to prepare tools for collection (See fig 4).
- When tool life signals 30 parts remaining, the tool life low limit warning light comes on, indicating to operator that a tool change is soon required.
- The operator is then required to walk to the tool crib to retrieve the new tool while there is still life on the old tool.
- A tool handover occurs between the operator and tool setter.
- Operator returns to machine with the new tool and follows the procedure of stopping the machine to insert the new tool, without removing the old tool as there should still be life on there.
- The machine cuts a part with the new tool and sends it for verification via operator hand gauging or CMM (depending on the type of tool).
- The machine continues to use the old tool until it is out of life.
- Providing that the part cut with the new tool has been deemed acceptable and acknowledged, the new tool will now become active.
- A signal light notifies the operator that the old tool has expired so they can stop the machine to remove it.
- The operator must then return the old tool by placing it onto an expired tool table located just outside the tool crib.
- Tool setters collect the old tools from the expired tool table so the holsters can be reused.

Variset4.TCS
Work List

Line: ☒ Hide Setup Tools

Descriptive ID	T No.	Machine	Current	Remaining	Predicted	Warning	Expected	Last Update	Setup
DGB-060-1007	T2329	OP 060.2	719	11	769	700	730	13/12/2019 10:28:01	☐
DGH-170-1011	T2366	OP 170.1	1119	16	1239	1105	1135	13/12/2019 10:32:28	☐
DGB-050-2013	T1564	OP 050.3	9968	32	10001	9970	10000	13/12/2019 10:32:07	☐
DGH-120-1007	T6128	OP 120.1	621	45	661	636	666	13/12/2019 10:31:57	☐
DGB-170-2003	T2657	OP 170.1	11150	59	11216	11179	11209	13/12/2019 10:31:27	☐
DGB-170-1005	T5133	OP 170.1	287	73	353	330	360	13/12/2019 10:31:29	☐
DGB-050-1011	T2653	OP 050.2	1589	67	1655	1626	1656	13/12/2019 10:32:31	☐
DGB-050-1003	T6108	OP 050.1	324	68	390	362	392	13/12/2019 10:30:40	☐
DGH-170-1006	T2166	OP 170.2	3790	69	3850	3829	3859	13/12/2019 10:30:48	☐
DGH-100-1013	T2363	OP 100.2	446	90	566	506	536	13/12/2019 10:30:32	☐

F4 - Print Print by Op F1 - Help F2 - Done

10:37
13/12/2019

Figure 4 – Tool Life Monitoring System

2.3 CONSEQUENCES OF THE PROBLEM

The consequences of this problem could develop in a 'domino-style' fashion, with the knock-on effect of a seemingly small problem causing Ford Motor Company more severe problems. If the problem continues to develop, and the JPH scores are not met on a more frequent basis, it could cost Ford both financially in terms of downtime and potential fines if assembly demands are not met and damage reputation if engine contracts were not fulfilled.

2.3.1 Cost of Losses

If production on the machining lines is stopped for any reason, there is a buffer of batch-built parts that can be used by Dragon assembly to ensure that assembly production continues. The target quantity of these batch parts is 150 of each product (Head, block and crankshaft), accounting for 5 hours of downtime. The actual figure varies due to downtime on both assembly and machining having an influence. Nonetheless, if the machining JPH scores are not being met consistently, then this will affect the number of batch units, resulting in a smaller buffer of parts available to assembly if machining is on stop.

If the suspected issues present in the tool change process continue to affect the JPH scores, then the quantity of batch-built parts will reduce over time. If this happens then a breakdown on the machining lines could result in assembly being on stop, losing out on 29 engines for every hour of downtime. Considering that the unit cost per engine is £1413.75 (Thomas, 2019), the cost of downtime per hour can be calculated to give the cost of the loss of business due to downtime:

$$\begin{aligned}\text{1 Hour of Downtime} &= 29 \text{ (Engines lost)} \times \text{£1413.75 (Unit cost)} \\ &= \text{£40998.75}\end{aligned}$$

In the event of the supply of parts to assembly being cut off, the line will run out whatever engines remain until it is empty. This means that when machined parts become available once more, it will be another hour until the next finished engine is pulled off as the line will have to fill back up to resume production.

$$\begin{aligned}\text{Cost of Loss of Business (2 Hours)} &= \text{£40998.75} + \text{£40998.75} \\ &= \text{£81997.50}\end{aligned}$$

The longer this problem is ignored, the more likely it becomes that it will develop to the point when assembly is interrupted regularly, costing Ford £82,000 per hour of downtime. Action must be taken to rectify the problems present with the current process to ensure that a sequence of events does not stem from it, potentially leading to assembly downtime which will damage the reputation of BEP among other Ford plants.

2.4 AIMS AND OBJECTIVES

Project Aim:

Design a new tool delivery system for a machining line that reduces the wastes present with the current process to ensure that targets are consistently met.

The following objectives have been set to ensure that the aim of the project is achieved. These are:

- **Research lean six sigma project tools to broaden knowledge for undertaking a project like this to ensure greater efficiency and overall success.**
- **Collect and measure the data surrounding the current tool change process to prove that there is sufficient waste present to warrant the feasibility of a new delivery system.**
- **Research and explore current autonomous vehicles technologies that fit operational requirements as well as Ford Motor Company specifications.**
- **Compare the cost of this new system against the introduction of an extra man to warrant the project.**
- **Research and develop an autonomous tool delivery system that will absorb much of the wastes associated with the current tool pick-up and return process.**
- **Implement the new delivery system into BEP and report any findings or issues present.**

2.5 VOICE OF THE CUSTOMER

In manufacturing, it is vital that any aspects regarding the customer are fully understood, as a misconception is to assume that the customer is the person who purchases a product. This is not strictly true as there are customers present at many different stages throughout the supply chain, both internal and external.

2.5.1 Internal Customer

Internal customers are those that are located in-house, in this case, within BEP. Dragon assembly would fall into this category as it relies on Dragon Head & Block machining to produce a constant flow of parts to ensure that engine targets can be fulfilled. Parts are built in batch quantities to account for downtime on the machining lines, however, if extended downtime leads to these parts being used, then assembly production will cease.

2.5.2 External Customer

External customers are usually the consumers of the product on offer, in this case, the Dragon 1.5L GTDI engine. These engines are built to fulfil contracts with Ford's vehicle assembly plants located in Cologne and Saarlouis in Germany. These contracts state the quantities required as well as the performance specifications that each engine should adhere to.

2.5.3 Voice of the Customer (VOC) Statement

The hourly JPH scores of the Dragon machining line are not being consistently met. The more this continues, the more likely it becomes that the supply of parts to Dragon assembly will cease, creating periods of downtime. If this were to happen consistently, then the consequences on BEP would be damaging both financially and in reputation.

3.0 LITERATURE REVIEW

The purpose of this section is to gather and critically appraise the relevant literature concerning the project. This provides the author with a greater understanding of the material surrounding the project and will enhance knowledge on the subject before the data collection and analysis being carried out. The literature must be critically appraised to justify its use, as well as to show that the authors are credible and recognised by others.

3.1 THE WASTES OF LEAN MANUFACTURING

Waste is defined as any activity that occurs during a manufacturing process that is not covered in the price of the product, therefore not being paid for by the customer. This means that these activities are taking place and driving up the costs of production, while sales remain the same, therefore eating into profit (Voehl, et al., 2014).

The 'Toyota Production System' (TPS) was a system developed by Toyota engineer Taiichi Ohno that built and developed the principle of lean manufacturing. This system focused on eliminating the three deviations of the inefficient distribution of resources: Muda (waste), Mura (unevenness) and Muri (overburden). Ohno, (1988) initially identified seven types of waste that should always be minimized to ensure an efficient manufacturing system, with an 8th being added years later when lean manufacturing had been developed into a worldwide tool within industry.

Transportation - According to Gay, (2016), transportation waste is the measurement of the movement of materials from one point to another. In some cases, the route taken during transportation is efficient but takes place in a poorly designed factory. Therefore, the waste produced by excessively transporting goods via a poorly planned route. This can enhance other forms of waste such as waiting or motion, as well as affecting 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 stock that has been overproduced, meaning that it is not required by the manufacturer at that current time. The overall cost of production will likely increase alongside this form of waste as excess stock will drive up costs to hold and transport (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.

Unnecessary Movement - This waste is defined as the waste produced by any physical movement that is carried out by a person working as part of a manufacturing process that is not necessary to the task

in hand. Examples of this are walking, reaching and bending. This type of waste can drive up the costs of a process by increasing the time taken for it to be completed (Gay, 2016).

Waiting - This type of waste occurs when work conducted 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 a knock-on effect that may increase waste in other categories. For example, if wait times are substantial then production may be rushed to meet deadlines, resulting in a more inferior standard of a product. This type of waste should not be overlooked as unnecessary wait times can accumulate over time and have a detrimental effect in the long run.

Over production - Ohno, (1988) deemed overproduction as the biggest problem that industries must put up with in terms of lean manufacturing. This type of waste occurs when the production of parts exceeds the demand or customer requirements. This type of waste has a knock-on effect on other types of waste such as inventory, transport, motion and possible defects as the unused stock will be stored in inventory. This drives up the transportation resources and storage costs of a product, whilst also increasing the risk of parts being damaged whilst in inventory.

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).

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).

Underutilising 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).

3.2 AUTOMATED GUIDED VEHICLES

3.2.1 Overview

Automated Guided Vehicle Systems (AGVS) were first invented in the 1950s (Mueller, 1983), with over 20,000 being used within industry by the year 2000 (Fazlollahtabar & Saidi-Mehrabad, 2015). Since then, they have been developed into an established method of organising modern intralogistics, initially in the automotive industry, but now they have been adopted by almost all forms of industry (Ullrich, 2015).

This type of system involves a computer-controlled, unmanned vehicle that can navigate with the use of various sensors and navigation beacons. These vehicles can be programmed to travel a defined pathway on a repeatable basis, making them ideal for the handling of materials across a repetitive route, particularly within factories (Castelberry, 1991) (Fazlollahtabar & Saidi-Mehrabad, 2015). The application of transporting materials through factories and warehouses from point to point was mentioned by Groover (2015), adding that there were four principal AGV applications for production and logistics; driverless train operations, storage and distribution, assembly-line applications and flexible manufacturing systems.

3.2.2 Types of Vehicles

According to Groover (2015), three types of AGV can be used for various purposes within industry: Driverless Train, Pallet Truck and Unit load carrier.

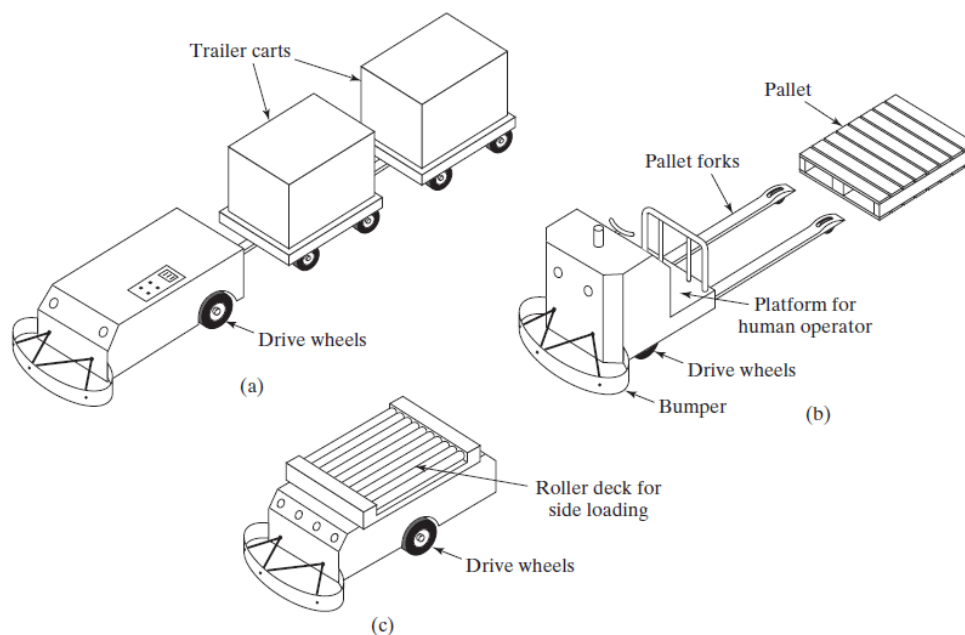


Figure 5 – The three types of AGV: (a) Driverless Train, (b) Pallet Truck, and (c) Unit Load Carrier

Driverless Train - The first type of AGV that was introduced in the 1950s was the driverless train that is used in instances in which the towing vehicle is used to pull single or multiple trailers in a train-like fashion (Groover, 2015) (Ullrich, 2015). Trailers can be attached and detached automatically and only require human interaction for loading. Once a towing AGV has reached its destination, it can detach the load and continue onto the next stop.

Pallet Truck – The second AGV variant is the pallet truck, that can be used for the transportation of palletised loads throughout a factory or warehouse (Fazlollahtabar & Saidi-Mehrabad, 2015). Since the introduction of this technology, it has been developed so that is essentially a driverless forklift. Groover (2015), mentions that this type of AGV requires some human interaction to locate the forks into pallets during loading, meaning it is not a fully automated system. However, the given the rate that technology is developing, full automation may not be that far away.

Unit Load Carrier - This form of AGV is used to transport unit loads between stations with the use of automatic loading and unloading facilities. Various means of automatic loading and unloading facilities can be built into this type of vehicle such as moving belts, powered rollers and lifting platforms (Groover, 2015).

3.2.3 Guidance Systems

The types of AGV guidance systems were listed by Groover, (2015) and Kostov, et al., (2015) as; imbedded guide wires, magnetic tape, laser-guided vehicles (LGVs) and inertial navigation. Due to the vast improvements in technology regarding AGV systems due to their rapid growth in modern industry, two more guidance systems have been developed since the publishing of the works by both Groover and Kostov, et al. in 2015. These newer guidance systems are; Vision guidance and geoguidance.

The findings of the research carried out by the project champion into the range of guidance systems previously mentioned will be discussed in the remainder of this section. (Groover, 2015) (AGVNetwork, 2019) (Neousys, 2019)

3.2.3.1 Imbedded Guide Wires

Wires are imbedded into the ground via a shallow cut channel then filled with cement to remove discontinuities to ensure a flat surface. This wire becomes part of a circuit which once energised, emits radio frequencies that are strong enough to be detected by the onboard sensor on the AGV. Multiple routes can be devised using this wire by constructing multiple circuits which can be switched between by energising the required route path to accommodate the destination. If the vehicle



Figure 6 – Imbedded Wire guidance system

somehow veers off course, it will be able to detect the drop of the radio frequencies and alter the steering until the wires are directly beneath once more. This limits the capabilities of the vehicle however, as it is limited to within a few feet of the imbedded pathway, meaning that routes cannot be easily modified once installed.

3.2.3.2 Magnetic Tape

This method of navigation is very similar to the previous method, with the difference being that it uses a magnetic tape on the road surface instead of imbedded wires beneath it. This allows pathways to be redefined in the event of a sudden change of requirements or floor plan layout. The other difference with this method is that the tape does not require a power source as the AGV does not require the emission of a power signal as the onboard computer will be able to select the desired route path. However, this means that the AGV will not be able to reposition itself if it is knocked off course.



Figure 7 – Magnetic Tape guidance system

3.2.3.3 Laser-Guided Vehicles

This method of navigation differs from the previous types as it allows the AGV to operate without the use of a defined pathway. This method uses a combination of reflective beacons that can be positioned around the desired route that will reflect the laser emitted by the vehicle back into a receiver, notifying the on-board computer that a beacon has been detected. Multiple beacons should be placed throughout the desired route for

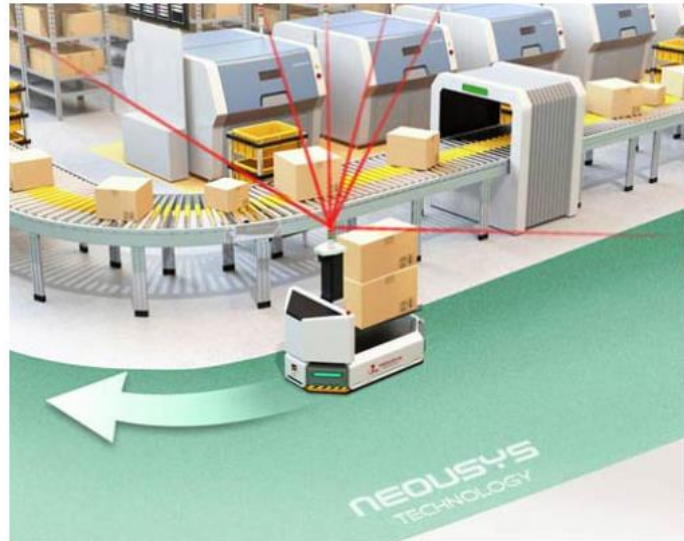


Figure 8 – Laser guidance system

this type of system so that beacons are detected frequently, allowing the on-board computer to calculate the known position of the vehicle using triangulation. This is then combined with a technique called 'Dead Reckoning' which uses an encoder that counts the number of wheel rotations and feeds the information to the on-board computer, which will be programmed to know the wheel rotations to distance ratio. A route can then be decided via computer software as the AGV will know what distance it must be from each beacon to ensure it is on the path, allowing more flexibility in route paths for the user.

3.2.3.4 Inertial Navigation

Similar to imbedded wire, this guidance method uses magnetic transponders that are imbedded into the floor to navigate. This strategy uses an onboard gyroscope as well as other onboard motion sensors to help navigate the vehicle from point to point. This differs from the imbedded wire navigation as this system allows the user to design a route path and upload it to the software, using the transponders as reference points. The onboard gyroscope



Figure 9 – Inertial navigation guidance system

and sensors can then detect the distance the AGV is from these transponders and cross-reference that with the computerised version to safeguard that the vehicle is following the path. This allows for a more flexible system as routes can be modified if needed via the computer software.

3.2.3.5 Vision Guidance/Geoguidance

These methods of guidance are very similar as both methods do not require any modifications to be made to the environment it will be operating in. The technology used in these systems is far more advanced than the other AGVs. These types of AGVs are equipped with cameras that record key aspects of a selected route and construct a 3D map of the environment. These key features include barriers, columns, racks and walls, which are essentially allowing the



Figure 10 – Vision guidance system

vehicle to see obstacles. A form of this technology, called Simultaneous Localisation and Mapping (SLAM) is revolutionising the AGV industry with Vision Guidance vehicles (VGVs), becoming more and more popular. It is predicted that SLAM guidance will completely take over from the more traditional types of AGV guidance systems as the main flaw was its high cost. However, these costs are ever decreasing as the availability of the technology required to produce it is advancing.

The use of an AGV was not a direct requirement by management; however, it has been deemed by the project team as a possible solution as its functions meet the criteria that could potentially solve the problem being faced. If selected as a solution, there are multiple FMC regulations that the vehicle must adhere to regarding safety, functionality and feasibility. These requirements will be addressed throughout the project and will likely be a critical deciding factor when deciding on the solution.

3.2.4 Fleet Size

In the literature surrounding AGVs and the number of vehicles required to operate in a system, it was stated by Groover (2015) that fleet size one of the most important aspects to consider during the designing of an Automated Guided Vehicle System (AGVS). Sinriech & Tanchoco (1992) support this, adding that the number of vehicles in a fleet must reflect on the system efficiently in terms of both workload and costs. This number can be obtained by using equations that include factors such as route distance, journeys per shift and vehicle speed. More recently, a study by Valmiki, et al. (2018) discovered that simulation methods could be conducted regarding fleet size, giving better results than calculations.

3.3. HEALTH AND SAFETY

In order to maintain a safe place of work, the Health and Safety at Work Act 1974 was imposed across all workplaces. This legislation sets out a structure that is mandatory for employers to enforce within their place of work in order to correctly manage the health and safety of every person present. The HASAWA 1974, commonly known as the 'Umbrella Act' due to how it covers the majority of existing safety legislation (CLR, 2018), defines the responsibilities of everyone in a workplace to ensure the safety of all involved. There are different variants of this act that apply to both employees and employers, both of which must be strictly followed.

Due to the possible inclusion of an Automated Guided Vehicle (AGV) as a possible solution for the problem stated at the start of the report, the relevant safety legislation must be researched. An AGV would come under the category of an industrial vehicle, so there are multiple relevant legislations. The Provision of Use of Work Equipment Regulations 1998 (PUWER) will apply to management within BEP, as they are liable for any work equipment, in this case the AGV. This legislation states:

"Equipment provided for use at work is:

- *safe for use, maintained in a safe condition and inspected to ensure it is correctly installed and does not subsequently deteriorate.*
- *accompanied by suitable health and safety measures, such as protective devices and controls. These will normally include emergency stop devices, adequate means of isolation from sources of energy, clearly visible markings and warning devices."*

- (HSE, 2020)

This means that there will be a duty of care placed on management if an AGV is used within BEP as the legislation states that they must maintain the equipment and ensure that it is properly fitted with the appropriate safety features. Due to the usage of electric personnel carrier vehicles that are used within Ford plants, which are similar in construction to an AGV, the procedures that are already in place for these vehicles could easily be adopted and applied to an AGV.

3.4 SIX SIGMA TOOLS AND METHODOLOGIES

3.4.1 DMAIC

DMAIC is an acronym for the five-phased approach to problem-solving and improving existing processes. These letters stand for Define, Measure, Analyse, Improve, Control and are all headings that represent the different stages that allow the user to break down a project into different sections (GoLeanSixSigma, 2017). These sections provide structure to the problem-solving approach, allowing for a faster and more efficient solution to problems in existing systems. Although a DMAIC project is displayed section by section, this does not mean that all work is carried out in that order as engineers will often be required to go back and forth to add information.

3.4.2 DMEDI

DMEDI is an acronym used for the six-sigma methodology applied to create and develop new processes, products and systems. This acronym stands for Define, Measure, Explore, Develop, Implement and like DMAIC are all headings for the separate processes that make up the methodology. This methodology differs from that of DMAIC as it focuses on creating and developing new methods as opposed to improving an existing one (Shankar, 2009). This approach is very similar to the DMADV approach of Design, Measure, Analyse, Design and Verify, which is also used for creating new processes (ASQ, 2019).

3.4.3 Comparing Methodologies

The following section details the different stages of both DMEDI and DMAIC projects (Jones, 2016) (ASQ, 2019) (SixSigmaDaily, 2019) (Terry, 2019).

Define – The Define phases of each of the six sigma methodologies are virtually the same as its purpose is to clearly state the problems that are present prior to the project being undertaken. The objective of this is to identify a problem so that it warrants the use for either a DMAIC or DMEDI project to improve conditions, results or constraints. The relationship between any business concerns including potential quality costs or consequences should also be addressed.

Measure - The Measure phases for each of the six-sigma techniques are also similar but do have slight differences which start to separate DMAIC and DMEDI. The measure phase in a DMEDI project requires a more thorough assessment as it will be paving the way for an entirely new process, as oppose to modifying a current process.

Explore vs Analyse – DMEDI's explore stage focuses on brainstorming ideas to act as a possible solution to the problem addressed during the design phase, exploring the technologies that are

relevant. The analyse stage focuses more on analysing the Measure stage to determine root causes of defects and areas of improvement.

Develop vs Improve – Whereas a DMAIC project team will start to focus on improving the performance of the existing process, a DMEDI project team will be developing and optimising a detailed design. This detailed design will focus primarily on meeting the needs of the customer to ensure a successful process

Implement vs Control – These stages are different again as the control stage of a DMAIC project will focus more on maintaining and monitoring a control measure. Whereas the implementation stage of a DMEDI project aims to achieve full scale implementation or place the appropriate steps in place in cases where implementing is not possible.

In most cases, engineers approach problems following the DMAIC method as it is the most popular approach. More often or not, problems cannot just be controlled, with root cause analysis pointing towards the idea of a completely new process all together. The project will then shift to a DMEDI format and focus more on exploring new methods as oppose to fine tuning the existing ones. This often leads to a larger scale project as a completely new process will be required to undergo further development and implementation (Kubiak, 2013).

For this project, the DMEDI format will be followed as it is more suited to the needs of the project scope, designing a new process. As the implementation of the project will not occur once this project has been complete, measures must be put in place for future implementation. Therefore the project team will be focussing on in-depth development that will require little or no later modifications.

3.4.4 Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effect Analysis is a systematic planning tool that is used to calculate the reliability and risks associated with a process, determining whether or not they should be a cause for concern (Anleitner, 2011). This tool is primarily based on achieving customer satisfaction by making sure that the likelihood of any failures occurring with a product has been considered and there are measures in place to prevent and reduce them, certifying product reliability (Stamatis, 2003). This is achieved using a table to calculate the numerous ways a product or process can potentially fail.

The FMEA prioritises actions using the Risk Priority Number (RPN) of each failure mode. This number is calculated by applying a score of 1-10 to three categories, with 10 being the worst case:

Severity (SEV): The impact of the failure in terms of financial costs and injury.

Occurrence (OCC): The frequency that the failure will occur.

Detectability (DET): The likeliness of the failure being detected using the current measures of control.

The RPN is calculated using the following equation:

$$\text{RPN} = \text{SEV} \times \text{OCC} \times \text{DET}$$

Figure 11 shows the layout of FMEA table and the categories that are used to identify any problems present with a design or process. The potential failure modes are prioritised based on the RPN, as the higher the RPN value, the more likely that failure mode is to cause problems with the system (Carlson, 2012).

Process Step / Input	Potential Failure Mode	Potential Failure Effects	SEVERITY	Potential Causes	OCCURRENCE	Current Controls	DETECTION	RPN
What is the process step and Input under investigation?	In what ways does the Key Input go wrong?	What is the impact on the Key Output Variables (Customer Requirements)?		What causes the Key Input to go wrong?		What are the existing controls and procedures (inspection and test) that prevent either the cause or the Failure Mode?		
								0
								0
								0

Figure 11 – FMEA Template Explained (Six Sigma DSI, 2019)

The use of an FMEA chart may be vital in developing a new process as it will allow to project champion to identify any flaws in the new design. If any flaws are present, they will be prioritised by the FMEA chart by the RPN, highlighting the aspects that need focusing on to ensure that time is not wasted on lower value tasks during development.

3.4.5 The 5S's

The 5S's is a widely recognised continuous improvement and lean manufacturing technique that is used in industry. This method originated in Japan, adopting some of the practices from the Toyota Production System (TPS) to establish the foundations for implementing the correct procedures to ensure a well-organised workplace (Brady, 2011). The basis of this method is to create an environment that focusses on keeping everything in the correct place (Ortiz, 2015). This can be achieved by breaking down an environment into pieces and focussing on each area individually, forming the 5S's (see figure 12):

- **Sort** - Seiri
- **Set** - Seiton
- **Shine** - Seiso
- **Standardise** - Seiketsu
- **Sustain** - Shitsuke

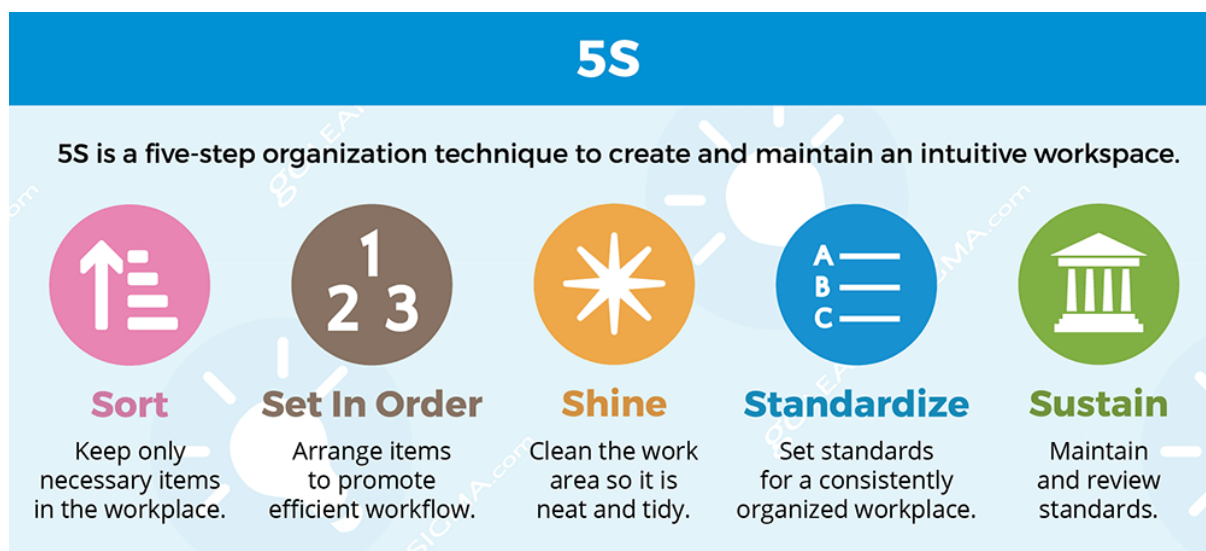


Figure 12 – The 5S (GoLeanSixSigma, 2020)

The purpose of this tool is to ensure that a workplace is well organised so that work can be carried out with minimal interruption due to bad housekeeping. Doing so enhances the safety aspect of a

workplace as the likelihood of an accident will increase with the amount of clutter that is present in a workplace (OSHA, 2002).

Although the project will not be implemented in BEP, if it is deemed a feasible solution by management, the steps can be taken to ensure that it can be implemented in other plants that produce the Dragon engine. This is a strong possibility as Ford uses a 'Bill of Process' system that focusses on standardising procedures that are put in place on a line across all plants. This means that if a change is made to the Dragon process in Bridgend, then it must also be implemented in the plants that produce Dragon in both China and Mexico. This highlights the importance of using the 5S's as doing so correctly will make the implementation of a new system far easier and reproducible for both the project team and for implementing into other plants.

3.4.6 Root Cause Analysis – Cause and Effect & 5 Why's

Root cause analysis is a strategy used in engineering for identifying the root causes of faults or problems that may be present in a system or process (George, et al., 2005). Two types of root cause analysis will be relevant for the concerns raised for the structure of this report, warranting a potential use for them later on.

The first type of root cause analysis method is the Cause and Effect diagram, also referred to as the 'Ishikawa' or 'Fishbone' diagram after its inventor Kaoru Ishikawa and the fact that the diagram resembles the skeleton of a fish. This diagram displays the problem as the head of the fish, with several branches of the categories that represent the main causes that contribute to make that problem. Each of these main causes will then have smaller potential causes branching off, symbolising the smaller bones of the fish (Tague, 2004).

The 5 Why's is a tool used to determine the root cause of a problem by simply asking why the problem is occurring. This repetitive strategy essentially interrogates the issue until the solution is found, with Tague, (2004) and Serrat, (2017) stating that five repetitions of 'why' directed towards a problem concludes answers that should get closer towards the source of the problem each time. Tague, (2004) then goes on to say how this method has been proven to be very effective over the years since it was first introduced, however Gitlow & Oppenheim, (1989) argue that it is not as effective in situations when the why is not known, so favour the Cause and Effect diagram. Serrat, (2017) supports this theory, adding that the 5 Why's can be a vague strategy as they have been known to come up with different causes for the same problem. Both authors however agreed that the use of the 5 Why's technique in conjunction with the Cause and Effect diagram will prove more successful as it will create a criteria to base the why's upon. This approach will definitely be considered by the project team while attempting to locate the exact source of the problem.

3.5 MANAGEMENT OF CULTURE CHANGE

In order for organisations to both achieve and maintain success, changes regarding operations, processes and employee practices are often required to move forward (Burnes, 2004). However, Harrington (2018) expresses that these changes alone are not enough to drive an organisation to success, as such changes must be accepted by those who will be working towards implementing them. Harrington (2018) goes on to state the importance of Culture Change Management (CCM), which emphasises the importance of people to make a change happen successfully. Eidelman, et al. (2010) and Cameron & Quinn (2006) support the importance of CCM and the fact that a change cannot take place if there are forces opposing it, the largest being the workforce who will be working towards implementing it.

The steps taken towards managing a change are essential, as humans are typically reluctant to change something that they have become accustomed to (Voehl, et al., 2016). This natural reluctance towards the introduction of a new process or system of doing things can prove toxic in a workplace, so it is essential that the correct steps are taken by management during implementation (Eidelman, et al., 2010). Therefore the 'Management of Change' has become a fundamental procedure throughout industry.

Kurt Lewin's Theory of Change model is a theory that has been developed since its introduction in 1947. This theory focusses on balancing the two main sets of behaviours that are experienced during any sort of organisational change: For and Against. Lewis theory is based on maintaining stability between these two sets of behaviours of people wanting to pursue a change and those who oppose it as they are happy as they are (Cummings & Worley, 2015).

The management of change is essential during the implementation of any new project and is a main focus point of the project team. It is likely that a detailed plan will be put in place as a result of consulting management about the final design of the new process to maintain the status-quo between employees to reduce any opposing force.

4.0 MEASURE: DATA COLLECTION

4.1 CAUSE AND EFFECT

Before the actual data collection stage of the project, it was decided that a better understanding of the problem was required to fully understand the causes. This required the project team to carry out numerous brainstorming activities to come to the assumptions necessary for the data collection (Bremer, et al., 2005).

A Cause and Effect diagram, also known as the 'Ishikawa' or 'Fishbone' diagram was produced for the project team to brainstorm ideas and assumptions as to what can harm the JPH scores of the machining lines (See Figure 13). This brainstorming tool is often used by engineers during the Define phase of a six-sigma project but can also be used to help identify factors that could be looked into during the Measure phase that could be the focus of the data collection. The problem that this project is based on will be the element that is 'Critical to Quality' (CTQ) and will be placed at the head of the fishbone diagram with the possible causes branching off under five sections; Process, Environment, Management, Workforce and Machines. From this, the project team were able to brainstorm each section and list multiple factors that may be contributing to the problem, proving to be CTQ (Bremer, et al., 2005).

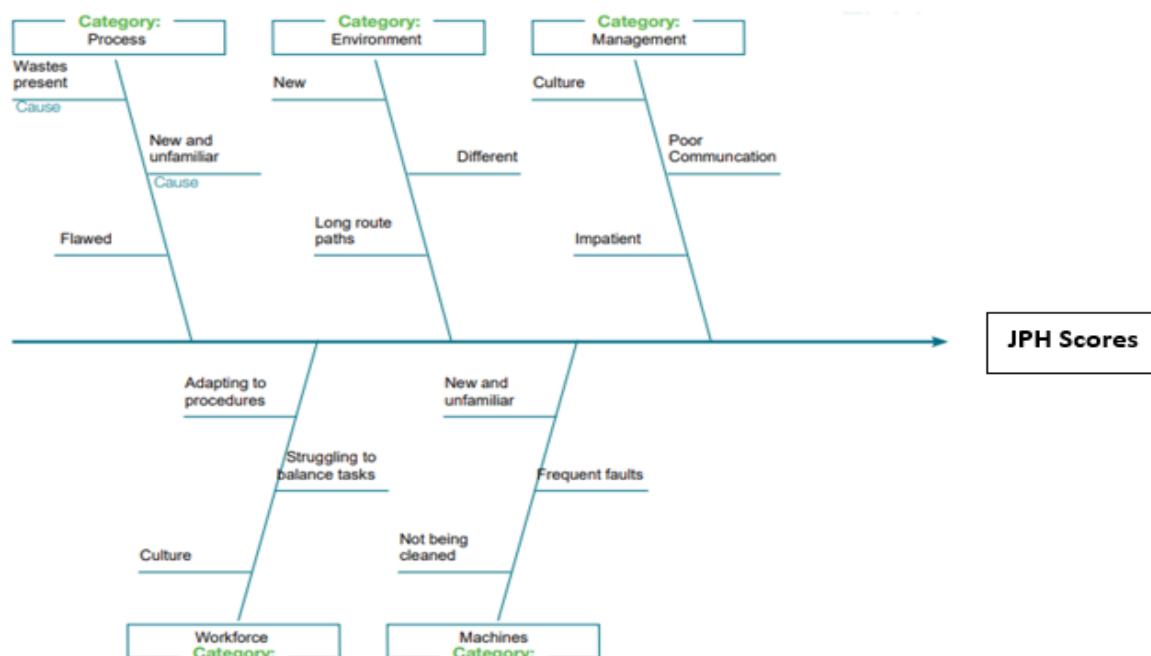


Figure 13 – Cause and Effect fishbone diagram

4.2 IDENTIFYING THE WASTES

When considering the 8 wastes of lean manufacturing that were discussed in the literature review (Ohno, 1988), it is apparent that there are various wastes associated with the current process. To further compile evidence of the waste present, so that the data collection aspect of the report can commence, the 8 wastes have been applied to the tool change process implemented on Dragon machining.

Transportation - This waste is present when operators leave their machine to walk to the tool crib to retrieve and return tools, often more on more than one occasion per shift. The initial thoughts that management displayed towards this tool change process were that operators would be able to walk to and from the tool crib as it is based next door to the line. This assumption caused a surplus of transportation waste as although nearby, the area of the line is quite large; 130m long and 87m wide (Jones, 2019). It appears that management underestimated the effect that this waste would have on production, opting to try and save money on the process.

Inventory - This type of waste is not present with the current process due to the nature of how the tool holsters are recycled efficiently to limit the money spent on them.

Unnecessary Movement - This waste occurs in the event where operators walk to the tool crib to retrieve a new tool and there is no tool setter present to serve them. While this is not a common occurrence, it does occasionally happen and although tool setters may have a valid reason to be absent from the tool crib during these periods, it is still an inconvenience to the operator conducting the tool change. In the event of this unnecessary movement, the operator performing the tool change will have to return to their machine and come back later. This waste enhances the likelihood of the old tool running out before the hand gauge or CMM check for the new tool has been approved, resulting in that machine being on stop until the inspection is complete. Considering the CNC machines have 2 or 3 machines per OP number, if one of these is on stop then the line will be running at a capacity of 50% or 66% respectively. Although this should only be for a brief period, it will create a bottleneck and could contribute to the problem of JPH targets being met.

Wait Times - The waiting waste for the tool change process occurs if operators are not immediately acknowledged by tool setters when they arrive at the tool crib to retrieve a new tool. Tools are not accessible for operators as they are stored on shelves within the tool crib, which is only available via a key card to the appropriate personnel such as tool crib employees and Dragon engineers (Drummond, 2019). This means that operators must wait at a counter for a tool setter so they can tell

them what tool they require. The tool setter can then retrieve the tool from the labelled shelves in the stock section of the tool crib and give to the operator.

The time taken for this exchange to occur counts towards the waiting waste present in the current system and although it may not seem like much, it will accumulate as a result of the thousands of tool changes that occur over a year. It is also not guaranteed that tool setters will be unoccupied and available to attend to operators straight away.

Overproduction - This type of waste has been known to occur in the event of multiple versions of the same tool being crafted as a result of a lack of communication between tool setters. This does not happen frequently enough to have an effect on the issues present with the tool change.

Over-processing - The only time this waste would occur is in the event of any defects being repaired as a result of human error e.g. a snapped tool or damaged holster from the tool being mishandled.

Defects - This type of waste can occur during the transportation of the tools. Although not a common occurrence, incidents have occurred when operators have damaged tools by dropping or catching them on something while walking back to their machines.

Underutilising Staff - This type of waste occurs due to the lack of skill required to walk to and from the tool crib to obtain and return tools. Considering that machine operators on Dragon are made up of IMS' and fully qualified maintenance personnel that have been put through countless training courses to enhance skills and knowledge, the skills that these employees possess are being wasted. If the time spent walking and waiting during current tool change process could be drastically reduced or even eliminated, then operators would have that time back to utilise their skills and time on relevant tasks, increasing employee productivity.

4.3 DATA COLLECTION PLAN

As mentioned in the DMEDI section of the literature review, the Measure phase is essential as this type of project focuses on building a new process virtually from nothing or an existing process with minimal definition. This section will primarily be centred around gathering the relevant data to prove the direct correlation between the tool change process and dip in productivity. This will then support the hypothesis discussed in the define stage, prompting management to act and find a solution.

4.3.1 What data will be collected?

The waste present with the tool change process mainly falls under transportation and employee utilisation, with wait times also being a factor during the handover of the new tool. Although there are only a few types of waste present, the accumulation of them has negatively impacted the JPH scores of the line, which in turn will likely influence product quality if not addressed accordingly. Therefore, the following data will be collected to identify how these wastes occur so that measures can be taken to prevent them in future processes.

4.3.1.1 Tool change frequency

To warrant the problem that was identified and defined previously, the rate of tool changes throughout the line can be used to prove the correlation between the utilisation of the operator's time and the dip in productions scores.

4.3.1.2 Transportation Waste

This data is directly related to the number of tool changes that are carried out by employees and will consist of the time it takes employees to walk to and from the tool crib. This data will account both retrieving the new tool and returning the old tool.

4.3.1.3 Wait Times/Unnecessary Movement Waste

A verbal survey will be carried with each operator on the machining lines across all shifts so that any additional time that may be present during a tool change can be documented. The frequency of wasted trips to the tool room will also be a talking point to account for the unnecessary movement waste. The average will be taken and added on to the total time of each trip so that the cost of the waste can be calculated.

4.3.1.4 Cost of Waste

Once all the time waste has been accounted for, it can be multiplied by the hourly rate of the operator to give an idea of how much money this waste is costing Ford. This data will also account for the amount of underutilising staff waste present with the process, as every second wasted by an operator carrying out a tool change is time that should be spent adding value to the product.

4.3.2 Why is this data required?

4.3.2.1 Tool change frequency

The data relating to the rate of tool changes will be used to give an estimate of the number of annual trips operators make to the tool crib. The TCF can be calculated for each machine operation which will determine the number of trips made by operators from each station throughout the working year. This data is vital as the figures obtained can be used for the remaining stages of the data collection phase and enhance the accuracy of them.

4.3.2.2 Transportation Waste

The data regarding the time taken to commute to the tool crib and back during tool changes is required to show the link between the current process and how it affects employee utilisation values. This correlation has yet to be proven due to this type of tool change process only recently being introduced. The time wasted can then be accumulated and added to the survey values to calculate the total cost of the wastes associated with each tool change.

4.3.2.3 Wait Times /Unnecessary Movement Waste

This data is essential and will enhance the accuracy of the results, therefore having a contribution to the project going forward. This data will allow the author to factor in the appropriate amount of additional time that accounts for real-life circumstances that are often left out of data collections. This time value will not be massive, but due to the high volume of tool changes that are carried out over the year, it will accumulate and impact results. The unnecessary movement waste is required to see if it more of a problem that it was initially thought.

4.3.2.4 Cost of Waste

This data is vital as it will likely be the contributing factor to warrant the use for the entire project. When management is presented with data that explains how much the poorly planned out existing process is costing them, they will have no choice but to act and look towards implementing a new system.

4.3.3 How will this data be collected?

4.3.3.1 Tool change frequency

The data regarding the frequency of tool changes on each of the machines used for the machining process will be obtained by contacting the engineer in charge of the tool crib as they have access to the data for every tool used on Dragon head and block machining. The tooling data can then be organised into 8 separate spreadsheets, one for each OP that is affected by the tool change process.

4.3.3.2 Transportation Waste

Due to the quantity and location of the CNC machines that require tool changes and the size of the machining lines, a set time cannot be used for determining transportation waste. Therefore, each route taken by an operator to get to and from the tool room will be walked and recorded. These routes will start at the relevant machine and finish at the tool crib and will be carried out for each OP that requires tool changes.

4.3.3.3 Wait Times/Unnecessary Movement Waste

A verbal survey will be conducted with every Dragon machining employee that is required to carry out a tool change. Questions will be asked regarding the frequency of wait times, how long on average they are required to wait and how often operators have to return at a later time to be served because there was no tool setter present in the tool crib.

4.3.3.4 Cost of Waste

The wastes present in the process can be combined to give a total value for the time wasted during tool changes. A calculation can then be constructed using the hourly rate of operators, the total time wasted and the frequency of tool changes to find the cost of the waste present in the tool change process.

4.3.4 Who will collect this data?

The author of this report will be gathering and documenting any data associated with the project. This data will be obtained as a result of directly communicating with the Dragon Machining workforce when they contribute via verbal surveys. Data will also be gathered through face to face contact and obtaining documents from senior engineers working at BEP.

4.3.5 When will the data be collected?

The data collection phase will be carried out in December 2019 over 2 months. Given that the tool data regarding TCFs is already documented and just requires organising, the bulk of the time will be delegated to timing the routes and implementing a survey to the workforce.

4.3.6 Where will data be collected from?

All required data will be gathered from the Dragon Machining area located within BEP. The TCF data will be collected from the Dragon Machining Engineering Offices, the transportation waste data can then be calculated from these values. The waiting and unnecessary movement waste will be obtained from the Head and Block lines from the workforce via primary research measures.

4.4 DATA COLLECTION RESULTS

For this section, data recorded will be displayed on a yearly basis to highlight the effect that the accumulation of the wastes can have, contributing to the total waste time and cost per year which will be helpful for any future cost analysis. The waste time per shift will also be displayed to prove how the wastes present with the current process have been affecting productivity.

4.4.1 Tool Change Frequency

A part is inserted into the machining line via the input station and travels throughout the length of the line, stopping at every station along the way. These stations consist of washes, CNC machines and hydraulic presses that each contribute to a step towards a fully machined part. Each of these steps is identifiable by an OP number and there can be multiple versions of the same machine for each OP. The washes and presses mostly stand at one machine per OP number, with the CNC machines having two or three machines per OP due to longer cycle times.

Every CNC machine that is used in the machining process has a set number of tools, each with a set 'Tool Life' that determines the number of parts that it can cut before being replaced. The Tool Change Frequency (TCF) of these tools is the number of times that the tool requires changing over all 678 shifts throughout the production year.

With the data obtained from Tooling Engineer Gareth Griffiths immediately after commencing with the data collection phase, the TCF per year could be obtained. The values shown in Table 1 are a sample taken from the full TCF database that can be viewed further in Appendix 1. The data shown in Table 2 displays the breakdown of the tool changes per year for each machine OP in a more understandable format.

Using the tooling data obtained from the TCF spreadsheet (See appendix) and the values calculated in the previous section of the report, the following data could be calculated. Table 2 shows the frequency of tool changes due to tool wear per machine yearly

$$\text{TCF [Yearly]} = (\text{Parts cut per year} \div \text{Number of machines}) / \text{TCF [Parts]}$$

$$\text{TCF [Shift]} = \text{TCF [Yearly]} / \text{Shifts per year}$$

Table 1 – Tool data sheet sample

Magazine/ Station #	Tool Number	TCF [Parts]	TCF [Yearly]
OP 50			
1005	1505	4412	13.3
1006	1508	4412	13.3
1007	9150	4412	13.3
1009	1707	22727	2.6
1010	1709	19608	3.0
1011	2653	1656	35.5
1012	7307	2200	26.7
1014	1550	5147	11.4
1015	2152	16779	3.5
1016	2150	18265	3.2
1018	1551	2694	21.8
1019	2654	7292	8.1
1020	4150	70028	0.8
1021	2655	6667	8.8
2001	1509	32609	1.8
2002	2123	10526	5.6
2003	4112	100000	0.6
2004	7318	12121	4.8
2005	2151	12956	4.5
2006	2650	14668	4.0
2007	2737	23333	2.5
2008	2738	41935	1.4
2011	2739	8389	7.0
2013	1564	22222	2.6
2014	2335	5714	10.3

Table 2 – Determining the TCF for each OP

TCF [Yearly] Total	236.9
Total x No. of machines (3)	710.7

Table 3 – Relevant figures for TCF calculations

Shifts per year	678
Parts per shift	260
Parts per year	176280

Using the tool data specific to each OP (See Appendix 1), the following data regarding the tool change frequency was calculated and is displayed in Table 4. It should be noted that these figures are based on each machine operation as opposed to each machine. The machine operation or OP is a collection of multiple CNC machines carrying out the same function to ensure some leeway for production in the event of breakdowns. This figure was then divided by 678, the number of production shifts per annum (see Table 3), to give a value for the amount of tool changes per shift.

Table 4 – Tool Change Frequency for each OP

Tool Change Frequency				
	Head		Block	
OP	Year	Shift	Year	Shift
50	710	1.1	632	0.9
60	X	X	993	1.5
100	614	0.9	753	1.1
120	3887	5.7	X	X
170	1242	1.8	711	1.1
Total	6453	9.5	3089	4.6

Table 5 – TCF Values

Tool Change Frequency		
	Year	Shift
Total	9542	14.1

From the data displayed in Table 4, it is clear to see that OP120 on the headline contributes to the most tool changes with 6 per shift. This number is significantly more than the other machines making it the contributing factor to the problem. It can also be seen that OP170 on the headline and OP60 on the block contribute to multiple tool changes per shift.

4.4.2 Transportation Waste

4.4.2.1 Route Times

Table 6 shows the time taken to walk from each OP on the machine line to the tool crib. It should be noted that these times were recorded during uninterrupted walks, this may differ during a tool change as the operator performing the task may encounter distractions along the way in the form of colleagues or supervisors. Times were converted to a decimal format to aid with the remaining calculations for the data collection stage.

Table 6 – Route times relevant to each OP

Walking Times (Minutes)		
OP	Head	Block
50	3.5	2.5
60	X	3.0
100	5.25	4.0
120	5.75	X
170	3.75	4.5

As already noted from the TCF data collected in the previous section, OP120 was the primary source of tool changes across both machining lines. This is understandable as this machine focuses on the intake and exhaust valve seats which consist of machining hardened material, speeding up the wearing process of the tools meaning that they have a shorter lifespan. The issue here is that the data collected from the timed walks in Table 6 depicts OP120 on the headline as the furthest machine from the tool crib, taking 5 minutes and 45 seconds to complete a round trip. Considering that the TCF data shows that there are on average, six tool changes per shift for that machine, this machine alone will contribute to a considerable portion of the waste.

Although it is less time consuming for operators to return multiple tools, this is not always an option as there could be significant periods between changes across a 12-hour shift. Waiting for extensive periods so multiple tools can be returned at once is not recommended by management as the tool crib require the tool holsters for the new tools.

4.4.2.2 Combining Data

Another aspect that must be factored in is how each machine operates a zero-loss system. This system ensures that there are no losses in production during a tool change by notifying the operator when the tool life is approaching zero. This small buffer gives them time to retrieve the tool and insert it into the machine. The machine then cuts one part with the new tool and sends it for hand gauging and in some cases a CMM check. The problem with this system is that it means that the operator conducting the tool change must make an additional trip to the tool crib to return the old tool instead of taking it with them when they make the first trip. The return trip was accounted for in the matrix shown in Table 7, multiplying each of the route times from Table 6 by a factor of 2.

It should be noted that the tool change frequency values have been rounded to the nearest whole number to simplify the calculations. This change will not manipulate results as the sum of the rounded values is 15, which would have been the value when the total TC per shift value of 14.2 (See Table 5) was rounded up as a tool change must be represented by a whole number.

Taking these new factors into account, the following equation was used to calculate the transportation waste time present with the current process.

$$\text{Transportation Waste (Shift)} = \text{TCF} \times (\text{Walking Time} \times 2)$$

Table 7 – Calculating the time wasted on transportation

Time Waste (Mins) Matrix		
OP	Head	Block
50	1 x (3.5 x 2) = 7	1 x (2.5 x 2) = 5
60	X	2 x (3 x 2) = 12
100	1 x (5.25 x 2) = 11.5	1 x (4 x 2) = 8
120	6 x (5.75 x 2) = 69	X
170	2 x (3.75 x 2) = 7.5	1 x (4.5 x 2) = 9
Total (mins)	95	22
	117	

From the data displayed in Table 7 that shows the TCF per shift, the yearly figure estimated can be found by multiplying each value by 678, the number of production shifts per year (See Table 3).

$$\text{Transportation Waste (Year)} = \text{Transportation Waste (Shift)} \times 678$$

Table 8 – Total time wasted on transportation over a production year

Time Waste (Mins) - Yearly		
OP	Head	Block
50	4746	3390
60	X	8136
100	7797	5424
120	46782	X
170	5085	6102
Total (mins)	64410	23052
	87462	
Total (hrs)	1457.7	

4.4.3 Wait Time/Unnecessary Movement Waste

The Dragon Head and Block machining lines consist of 64 employees, 48 IMS and 16 maintenance personnel who all operate the machines discussed in this report on a rotating basis. The goal was to ask each employee about their experiences with the tool change process and the waiting times and unnecessary trips associated with the tool crib. However, due to the effects of the COVID-19 pandemic, the temporary closure of BEP meant that this collection of data was unable to be completed.

Out of the 64 employees on Dragon machining, 21 were able to participate in verbal interviews regarding the waiting times (WT) and unnecessary movements (UM) that are present with the current process, given the situation. Out of those interviewed, the answers were relatively consistent with employees stating that wait times are mostly between 5 and 20 seconds. However, incidents in which waiting times exceeded a minute were also addressed and also the times when there was no tool setter present, resulting in a second trip were also mentioned to occur frequently.

When reviewing the data gathered from a third of the workforce, the decision was made to include 1 minute onto each tool change to account for the waiting time and unnecessary movement waste. This assumption was deemed to be a fair reflection on the process as it balances the numerous short waits with the long waits and multiple trips. Although this value may not seem like much, it will accumulate over the year due to the high frequency of tool changes and influence the total cost of the wastes present in the tool change process.

Considering that a minute was added for each tool change to account for a combination of the waiting time and unnecessary movement wastes present with the tool change process, the following figures can be derived from Table 5 in the TCF section of the report:

Table 9 – Waiting and Unnecessary Movement wastes

WT/UM Waste		
	Year	Shift
Total (mins)	9542	15
Total (hrs)	159	0.25

To conclude, the data presented in Tables 4,5 and 6, the total cost of the wastes could be calculated using the following equation:

$$\text{Total Waste} = \text{Transportation Waste} + \text{WT/UM Waste}$$

Table 10 – Combining Transportation and Wait Time/Unnecessary Movement wastes

Total Wastes		
	Year	Shift
Total Value (mins)	87462 + 9542 = 97004	117 + 15 = 132
Total Value (hrs)	1457.7 + 159 = 1616.7	1.95 + 0.25 = 2.2

4.4.4 Cost of Wastes

From the data gathered in the previous sections, regarding the time that is being occupied by the wastes present with the current process, the money spent on paying employees to essentially do nothing to contribute to the quality of the product can be calculated. Considering that the hourly rate for an operator within Ford is around £22 an hour including shift allowance, IMT and other add-ons (Williams, 2020), the cost of the wastes can be calculated using the values from Table 8 and Table 9:

$$\text{Transportation Waste Cost (Year)} = \text{Total Transportation Waste (Hrs)} \times \text{Hourly Rate}$$

$$= 1457.7 \times \text{£}22$$

$$= \text{£}32068.40$$

$$\text{WT/UM Waste Cost (Year)} = \text{Total Waiting Waste (Hrs)} \times \text{Hourly Rate}$$

$$= 159 \times \text{£}22$$

$$= \text{£}3498.00$$

$$\text{Total Waste Cost} = \text{£}32068.40 + \text{£}3498.00$$

$$= \text{£}35566.40$$

4.5 REVIEWING DATA

The data gathered during this collection stage of the project is critical as it highlights the costs present due to the wastes associated with the tool change process on the Dragon machining lines. Not only are these wastes costing Ford over £30,000 per year in wages, but they are also taking up over a thousand hours of employees contracted working hours and affecting employee productivity.

The results displayed are purely statistical as they have been derived from tool data spreadsheets that show the lifespan of each tool and not the actual number of tool changes that have been carried out on the lines. Regardless of this, it was decided by the project team that this data collection method would be far more accurate than the second option of collecting tool change frequencies from logbooks over a smaller time window and superimposing these values over an extended period to show the data.

4.5.1 Real-life Factors

When looking at the tool change data, a misconception could be to assume that because the data displays OP120 as having the most tool changes, therefore equating to more time and cost wastes, the problem could be resolved by focussing purely on that machine operation. Although not entirely wrong, this assumption would be incorrect as this data is purely statistical and does not consider factors that may occur in real-life circumstances that may increase the tool changes for other machine OPs. For example, firstly tool breakages have not been considered and secondly, the TCF data is displayed in a manner that depicts the tool changes being carried out with equal time increments between each tool change.

To account for these factors and therefore improve the accuracy of results, the decision was made to create a scenario that may be more likely to occur in actuality. This scenario would contribute to the data collection by calculating the waste time present with a set number of tool changes per machine that reflect on an average shift. This value was agreed upon after consulting supervisors and team leaders so that they may suggest an amount that they feel suits the scenario.

4.5.2 Scenario

4.5.2.1 Concept

To enhance the accuracy of the data collection, a discussion took place involving the project champion, foreman and team leader. The purpose of this discussion was to agree on a scenario that best reflects the actual number of tool changes that occurs on the majority of shifts.

After being shown the data collection results, Cresswell, (2019) and Williams, (2019) concluded that although the results were reasonably accurate, a scenario in which every machine underwent two tool changes throughout a standard 12-hour shift was better suited. It was also agreed that six tool changes (2 per machine) on OP120 would stay the same as that value was a fair reflection on reality, leaving the total number of tool changes at 20. Although this scenario does not apply to every shift, it was deemed to be a realistic occurrence as operators would often experience this, as well as shifts that required no tool changes on some machines. This shows that the data collection results were likely correct in total. Still, the occurrence of tool changes is not distributed evenly, as in reality, employees experience high and low tool change frequency shifts.

The high value of 20 tool changes per shift will be used in this scenario, as any planning going forward should always be based on the worst-case scenario. The waiting time waste will remain at 1 minute per tool change for this scenario, meaning that 20 minutes will be added on to the total value to account for this waste.

$$\text{Total Waste} = (\text{Walking Time} \times 2) \times \text{Occurrence} + \text{Wait Time}$$

Table 11 – Wastes present with the real-life scenario

Scenario Waste Matrix		
OP	Head	Block
50	$(3.5 \times 2) \times 2$ = 14	$(2.5 \times 2) \times 2$ = 10
60	X	$(3 \times 2) \times 2$ = 12
100	$(5.25 \times 2) \times 2$ = 21	$(4 \times 2) \times 2$ = 16
120	$(5.75 \times 2) \times 6$ = 69	X
170	$(3.75 \times 2) \times 2$ = 15	$(4.5 \times 2) \times 2$ = 18
Total (mins)	119	56
	175 (+ 20) = 195	
Total (Hrs)	3.25	

The total waste that is present due to tool changes in a 12-hour shift that was calculated using the tool data spreadsheet was found to be 132 minutes (2.2 hours), as displayed in Table 10. This figure will be referred to as 'Value A' for this section for clarity purposes. The scenario that included a set number of tool changes as decided as a result of a consultation between the project champion, supervisors and team leaders, found that this value had now increased to 195 minutes (3.25 hours) of waste. This figure will be referred to as 'Value B'.

4.5.2.2 Comparing to statistical data

When comparing these results, it should be noted that Value A is the estimated average. In contrast, the Value B figure is a frequent occurrence, meaning that although there are often two tool changes per machine in a shift, this does not happen all of the time. Out of the additional 63 minutes that appear in Value B, it is worth mentioning that only a partial amount of this will be due to tool breakages, implying that this value will not simply mean an additional 63 minutes being added to the waste time for every shift. This being as it was previously mentioned that tool changes would not be evenly distributed, with consistent time increments between each change. This means that in reality, the waste time should oscillate around the benchmark of the statistical value of 132 minutes, with the frequency of tool changes experiencing high and low days.

4.5.2.3 Concluding Findings

The concern with this scenario is not the additional cost of wasted labour per shift, but more the fact that out of a 12-hour shift, 3.25 hours are being wasted transporting tools. This is time that could be spent on tasks that contribute to the machining process, such as cleaning machines to ensure that the swarf build ups do not interfere with machine operation.

This scenario was primarily structured around the data collection results, with the input from supervisors and team leaders contributing to the scenario that reflected the reality of the tool change frequency. Based on the waste quantities derived from the data collection phase as a whole, the problem definition has been supported. This is not acceptable for a company like Ford, who try and encourage lean manufacturing in all of its plants across the globe.

4.6 TOTAL COST OF THE PROBLEM

The total costs of the wastes within the current system can be estimated by using the values gathered during the data collection phase and the cost of downtime that was mentioned in Section 3.3.1 in the Define phase. The 'Cost of Loss of Business' was concluded to be £82,000 if assembly were to cease production for an hour completely. If the problem initially addressed at the start of this project were to lead to assembly being on stop for just 5 hours throughout a whole year, a figure that was deemed to be an appropriate assumption by Williams, (2019), then the total costs would be as follows:

Costs Due to Downtime

$$= 5 \times £82,000$$

$$= £410,000$$

This figure will then be added on top of the £35,566.40 wage costs relevant to the wastes in the system to give a combined annual total.

Total Annual Losses

$$= £410,000 + £35,566.40$$

$$= £445,566.40$$

5.0 EXPLORE: CURRENT TECHNOLOGIES

5.1 IMPACT OF THE DATA

The Explore phase of the DMEDI approach is used to explore the many options that are available that would contribute to a new process altogether. These options, whether latest technology, procedures or overall approach to the way things are done can then be combined to create a conceptual design that could potentially pave the way to a new process that maintains the quality of work, therefore satisfying the customer.

The VOC statement reads: *The hourly JPH scores of the Dragon machining line are not consistently met. The more this continues, the more likely it becomes that the supply of parts to Dragon assembly will cease, creating periods of downtime. If this were to happen consistently, then the consequences on BEP would be damaging both financially and in reputation.*

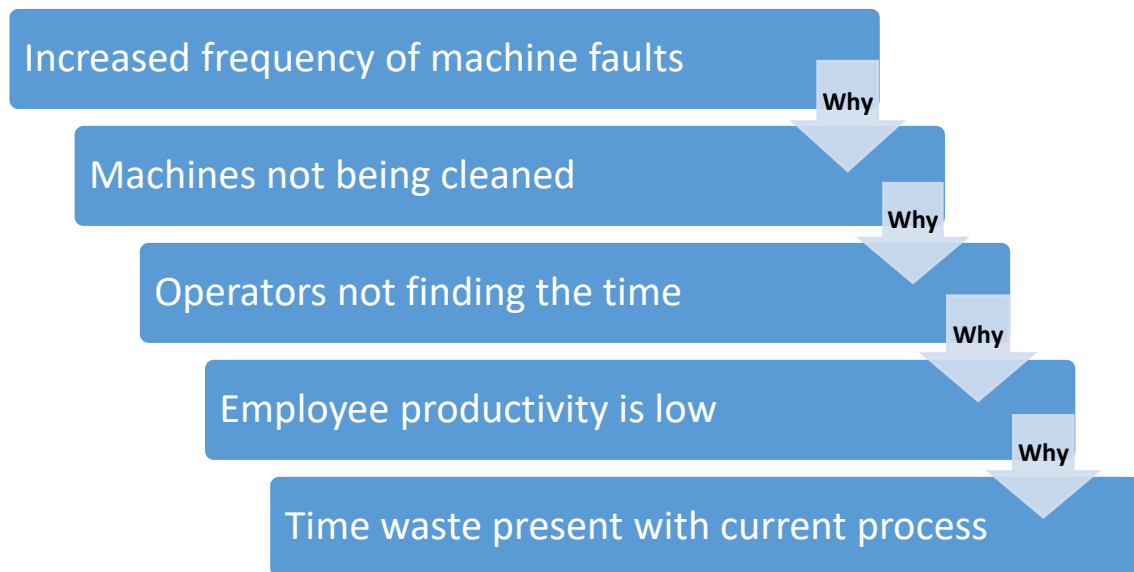
Regarding this statement, it was estimated in the data collection that the cost of the wastes was around £35,000 a year, with a further £410,000 being added on if assembly was to experience just 5 hours of downtime as a result of the problem discussed in this report. The chances of this happening increase every time the hourly line scores are not met, which will continue to happen more frequently if nothing is done about the wastes present with the current tool change process.

To further examine the problem and the consequences that come with it, the 5 Why's root cause analysis strategy will be conducted to prove further the effect the wastes can have on production. Once the results of these strategies have been concluded, research regarding potential solutions for the problem will be conducted further.

5.2 ROOT CAUSE ANALYSIS

As discussed in the literature review, the 5 Why's is a technique used to carry out root cause analysis. This technique was used to determine the root cause of the problem so that action can be taken to prevent the problem from occurring in the new process.

Problem Statement: Why are JPH scores not being met?



Root Cause: Inefficient, time-consuming tool change process

Proposed Corrective Action: Explore methods of increasing resources

Figure 14 shows a detailed version of the knock-on effects and consequences of the problem if left untreated.

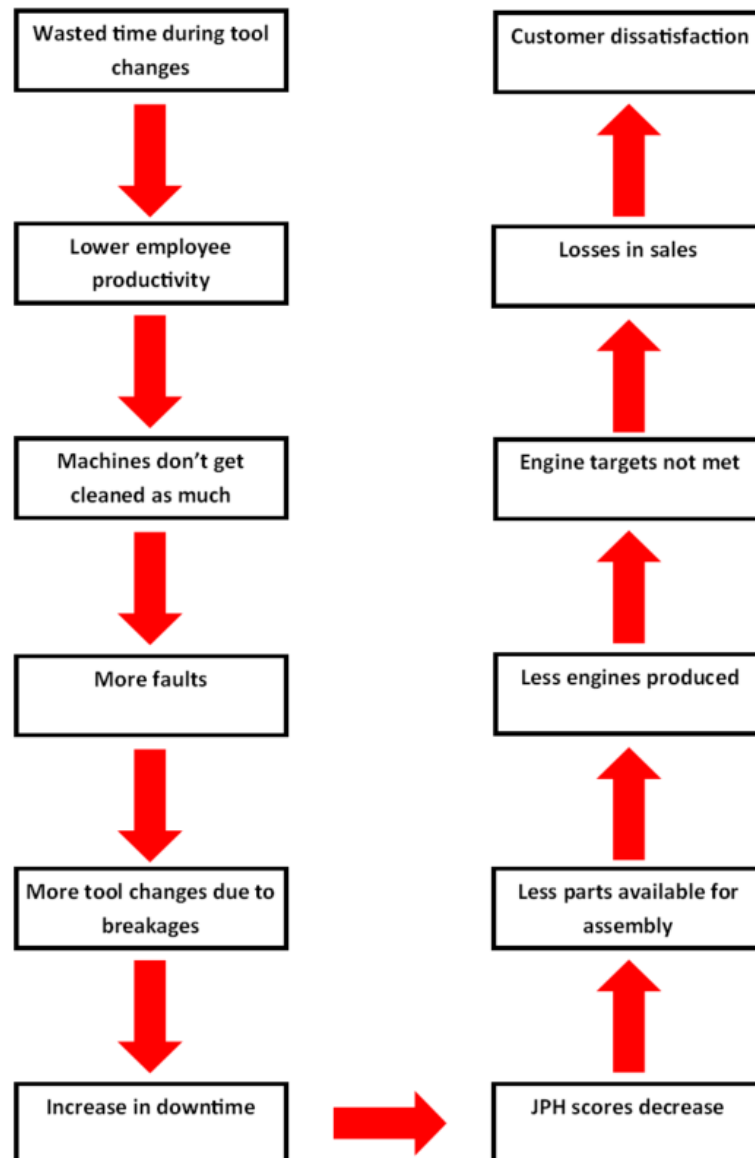


Figure 14 – Consequences of problem flowchart

5.3 PROPOSED CORRECTIVE ACTION

This section of the report aims to explore two different methods of action that could be taken to solve the root cause of the problem. These possible solutions will be investigated and compared to conclude the technique that will be investigated further throughout the report.

5.3.1 Extra Labour

One option that could be pursued to reduce the wastes present with the current service would be to simply include another employee to the tool crib to help balance the workload and contribute to the tool deliveries on foot or via battery-operated Tow Tug. The cost of this strategy could be calculated using the annual cost of an operator, including pension and holidays totalling £72,000 (Moreton, 2019). This value would then be multiplied by the number of extra men required, which would likely be one for each shift, four in total.

Cost of Extra Labour

$$= \text{£72,000 (Tool Setter Annual Costs)} \times 4 \text{ (1 man per shift)}$$

$$= \text{£288,000}$$

The total cost of the wastes present was estimated to be around £455,000 a year if left untreated, meaning that this strategy would provide a cost-saving. However, it feels like this approach would be drastically overcompensating, considering the operational requirements of around 20 tool changes per shift, as displayed in section 4.4.1.1. Although the problem addressed in the Define phase of this project would be solved, the project team concluded that this solution would not be in the best interests of management, recommending further research into an alternative method. This being the introduction of a new employee would be unnecessary as they would be heavily underutilised due to the current numbers in the tool crib. This would likely create more problems down the line due to the current shortage of skilled trade in BEP. This solution would also create a dilemma as the workload that is being placed on the current tool setters is too great for them to delegate time to deliver tools, but not enough to warrant an extra four men being added to the area.

5.3.2 Automated Guided Vehicles

The other option is to introduce an Automated Guided Vehicle (AGV) to BEP with the sole purpose of delivering tools to workstations. Groover, (2015) stated that an AGV system is most applicable to the moving of materials through various load and unload points. From the data collection, it can be seen that the high frequency of repetitive trips to and from the tool crib fit the requirements for an AGV system, applying to the scenario that is present in this report.

The introduction of an AGV into the current tool change system would not eliminate the wastes; it would absorb the majority of them, taking on the burden of the waste so employees can utilise their time on relevant tasks.

5.3.3 Conclusion

On reviewing the data that has been presented in the Measure section, that displays the manner and severity in which various wastes have been occurring, it was decided by the project team that an AGV would be the focusing point of the Explore phase. This decision was partly influenced by the facts that the Emerging Technologies department specialise in bringing the newest innovative technologies to BEP to utilise within the plant. The department has been looking at introducing AGVs into Bridgend for a while but has not been able to define a reason to warrant such an investment. The primary influence of this decision, however, was down to how the option of extra labour would defeat the object of the decision initially made at the start of Dragon to avoid over manning the tool crib.

Therefore, the remainder of the section will be devoted to researching the modern cutting edge AGV technologies that are available on today's market. This research will be carried out by the project champion, with the aim being to explore the different AGV technologies and find the most suitable product to act as a solution to the problem being faced. Once this has been achieved, a conceptual design for a new process can be designed and priced up. Cost analysis can then be carried out to compare the costs of the AGV method to additional labour to see which is the better and more cost-efficient strategy.

Due to the announcement that Ford plans to close BEP in late 2020, this project will not be implemented within Bridgend. However, the project team is still devoting the same amount of time and resources to exploring the best innovative AGV technologies that would provide a solution to the problem being faced. This being as if the project is carried out correctly, it could still be implemented in other Ford engine plants that produce the Dragon engine.

5.4 AGV SELECTION

5.4.1 Operational Requirements

When considering products during the AGV selection stage, the operational requirements (OR) of the project must be addressed before any more work is conducted into the selection process. These requirements are an essential tool for developing projects and new procedures as they help the user identify the critical aspects of the project that must be adhered to. CPNI (2018) expressed that the success rate of projects that have abided to following operational requirements as a guideline is significantly higher. This statement makes sense as it is essentially a format to ensure that the critical elements of a product that would be most suitable for the task in hand are prioritised, ensuring that money is not wasted on features that would not be fully utilised.

5.4.1.1 Route Distances

Due to the Dragon machining line being one of Ford's newest products, the security measures regarding detailed line drawings and layouts are higher than other areas of BEP. These measures were then tightened as a result of the proposed closure of BEP as the Dragon line would be moving to a different FMC Engine Plant. This means that the detailed layout of the lines could not be obtained for this report. However, the values regarding the distances between each machine operation and the tool crib were obtained by consulting the Dragon machining process engineer, Paul Rosser, (2020) and using the measurement scale provided with the official FMC floor plan. These values can be seen in table 12 and include the return path, with figure 15 showing an unofficial line layout that was created specifically for this report. Each route distance was taken from the front of the tool crib to the centre of each cluster of machines.

Table 12 – Route path distance from the tool crib to each machine OP (round trip)

Route Distance (m)		
OP	Head	Block
50	612	106
60	X	126
100	452	276
120	438	X
170	318	422

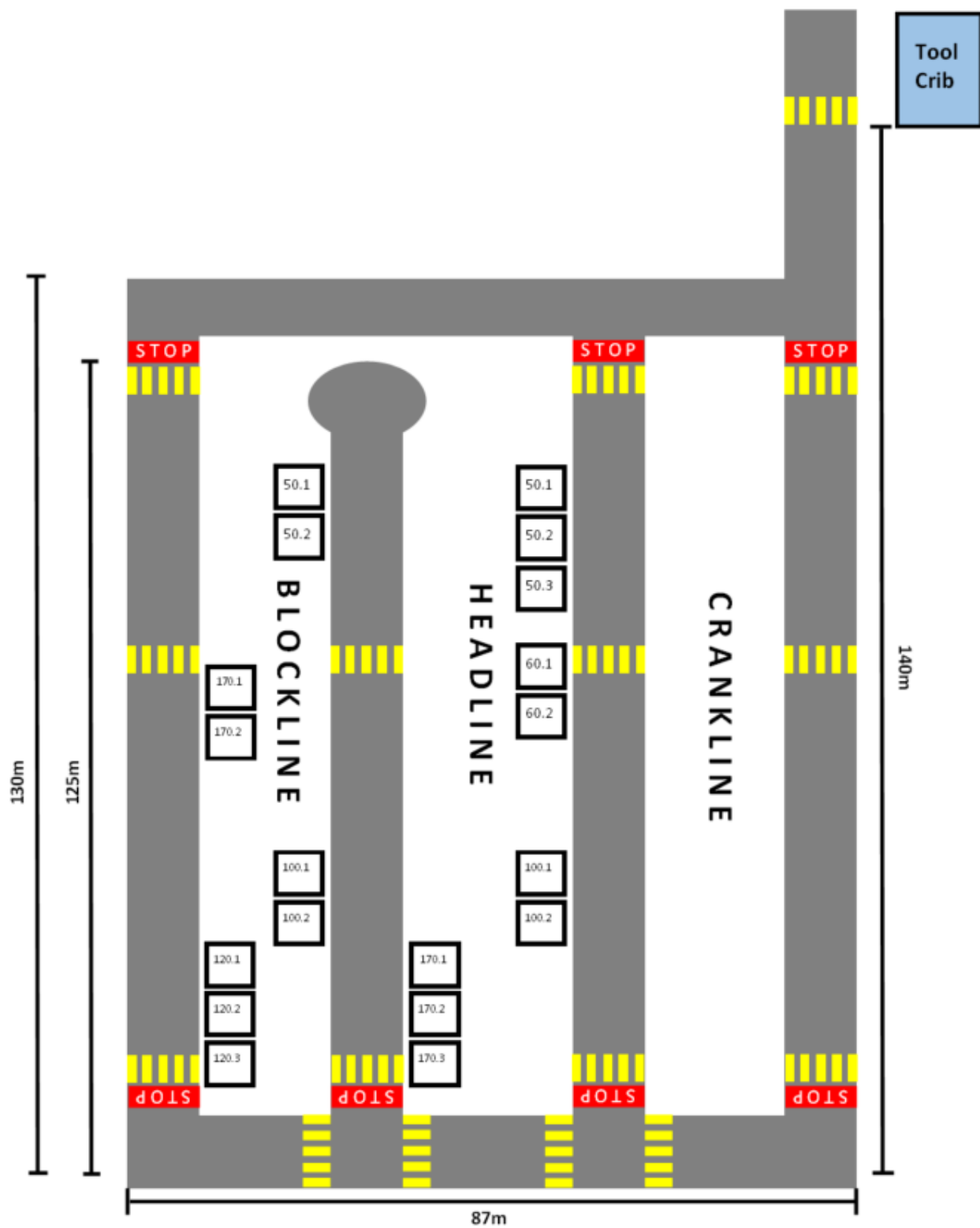


Figure 15 – Dragon Machining line layout

5.4.1.2 From-To Chart

As stated by Groover (2015): “a From-To chart is a tool used to indicate the material flow data and distances between multiple locations”. Therefore, by using the distances of each path from table 13, the following From-To chart could be constructed to help conclude the journey requirements of an AGV per shift. The chart shown in figure 16 uses the tool change frequency values that were addressed in the scenario described in section 4.4.1.1. These values have then been multiplied by the distance values in Table 13 to give to distance travelled per shift, relevant to each machine operation.

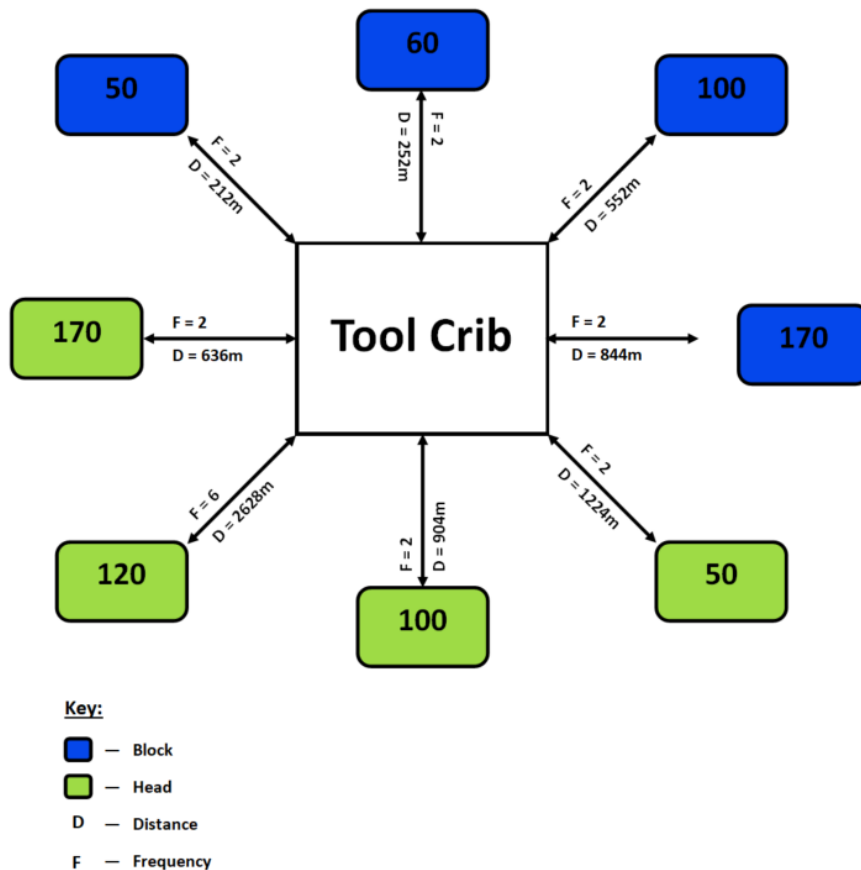


Figure 16 - From-To Chart detailing the tool changes per shift

Going off the values included in the From-To chart, an AGV would be required to travel around 7250m per shift. This value can be used to estimate the duration in which an AGV will be in operation over a shift by dividing it by the AGV speed. Given that the average speed of the AGV products collected for the selection process (see figure 21) was 1 m/s, that value will be used to calculate the operation time per shift.

Operating Time

$$= 7250\text{m} \div 1 \text{ m/s}$$

$$= 7250\text{s} \equiv 125.33 \text{ mins} \equiv 2.09 \text{ hrs}$$

5.4.1.3 Vehicle Type

As mentioned in section 2.1 of the literature review, there are three types of AGV that all suit different purposes. When considering the operational requirements associated with this project, the type of AGV suited to this project is the driverless train. This category of AGV was discussed by Groover, (2015) and Ullrich, (2015) as being suited to pulling single or multiple trailers in a train-like fashion. These trailers can be attached and detached automatically and only require human interaction for loading. Once a towing AGV has reached its destination, it can separate the load and continue onto the next stop. This motion will be used in the new tool delivery system, with the AGV travelling from point to point between the tool crib and machine operations.

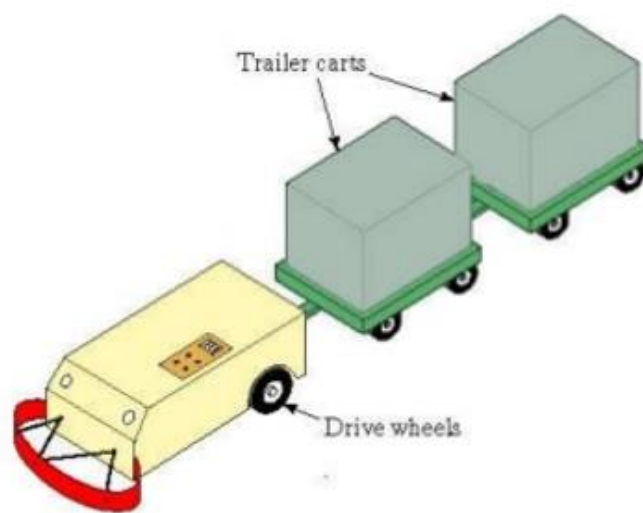


Figure 17 – Driverless train AGV (Groover, 2015)

5.4.2 Vehicle Guidance

The vehicle guidance system determines how the AGV navigates from one point to another, as well as its ability to overcome any obstacles. This is a fundamental aspect of an AGV system; therefore, the decision was made by the project team to investigate each type of navigation system available on today's market. Before this could be achieved, further research was conducted into the field of AGV guidance systems to determine the different types, as well as their functions and applications.

Five different variants of guidance systems were discussed in the literature review, each with different traits and features to accommodate a wide range of customers. These findings were extensively reviewed by the project team to determine the best solution for the project going forward regarding costs, practicality and safety. Whitelock, (2020), explained that management was firmly against the idea of making any modifications to the road layout that is currently implemented in BEP.

Whitelock, (2020) then went on to explain the decision, stating that the roads could not be dug into to imbed wire or transponders and the magnetic tape would interfere with road markings put in place to enhance employee safety (see figure 18). Therefore, only laser or vision-guided vehicle systems will be considered when selecting the AGV fit for the project.



Figure 18 - BEP road safety markings

5.4.3 Battery Project

Certain projects that are undertaken by Ford engineers, particularly those working within the Emerging Technologies (ET) department, are deemed classified to anyone outside of the department working on it to prevent the occurrence of ideas being leaked and copied by competitors in the automotive industry. Moreton (2019) explained that due to this FMC security policy, the 'Battery Project' that the Emerging Technology department has been working on could not be discussed in full detail. However, Moreton (2019) then went on to explain the aspects of the project which were not subject to security concerns, which will be discussed throughout the remainder of this section of the report.

Since the start of the project in January 2019, 28 used EOL Electric/Hybrid vehicles, or single battery packs have been shipped to BEP for the ET department to utilise for second-life purposes instead of Ford having to pay around £1000 to dispose of them. This surplus of batteries could hugely benefit this project if the batteries can be used effectively as part of the proposed AGV system, bringing purpose to the second-life batteries and potentially reducing the costs associated with the project.

5.4.3.1 Second-Life Usage

The project focuses on utilising old batteries from electric vehicles for a variety of different cost-saving projects within BEP. Despite these batteries being referred to as 'old' or 'used', that is far from the case. According to Saxena, et al. (2015), battery packs are deemed unfit for an electric vehicle when its life has diminished by 15-20% as this drop in capacity will affect acceleration, range and the regeneration capabilities of the vehicle, rendering it unfit for traction.

To ensure that the batteries obtained by the ET department were acceptable for second-life usage, they were subjected to a Load/Capacity evaluation process as well as Max/Min Charge Cycle Testing to ascertain Charge Capacity (Energy) remaining concerning the age/mileage of batteries was acceptable. The results of these tests determined that all of the batteries being held in BEP were deemed suitable for 2nd life applications, with the remaining battery life averaging out at 75%.

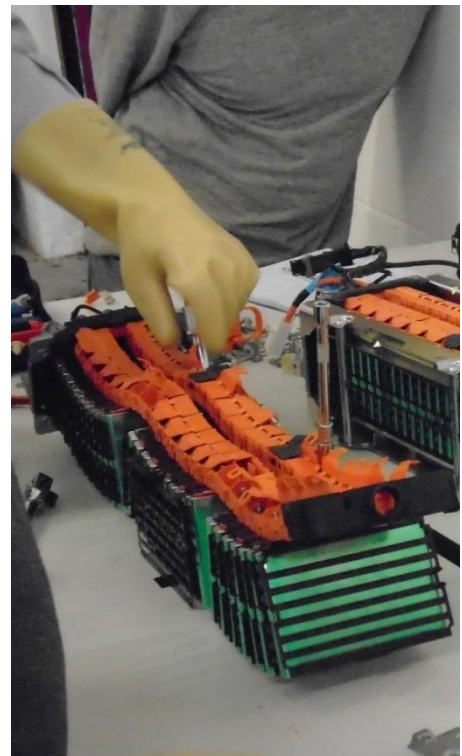


Figure 19 – Battery cell testing in BEP

BEP's ET Engineer in charge of the battery project, Kevin Greening (2020) was satisfied with the results from these tests, stating that the batteries were fit for use in BEP. An investigation by Sanghai, et al.

(2019) into the safe applications of second-life batteries found that they retain around 80% of their original capacity. This will be useful providing that their second application is not as demanding as its original, thus complying with the findings of Saxena, et al. (2015), showing that the in-house tests were of relevance.

5.4.3.2 Disadvantages

Before deciding on whether or not the second-life batteries would be used for this project, more research was conducted into the disadvantages that have been associated with their usage. Firstly, Broussely, et al. (2005) found that there are factors such as anode deformation, copper corrosion and electrolyte oxidation that occur during the ageing of lithium-ion batteries that may result in heat loss that will affect the efficiency of the battery. This will likely affect the performance and charge times of the battery and will be considered by the project team when deciding on using second-life batteries.

Secondly, an investigation by Hawkins, et al. (2013) showed that fast-charging batteries should be avoided if trying to prolong the life of them, stating a direct correlation with the battery degradation rapidly accelerating with the increase in charging current. This eliminates the possibility of ever installing a fast-charging point to quickly recharge the AGV if the operational requirements per shift increase for any reason.

5.4.3.3 Advantages

Whereas the second-life lithium-ion batteries may not warrant the performance capabilities of a new one, as apparent in the previous section, their availability may compensate for this. The ET department is already in possession of 28 batteries with no purpose with 18 of these being directly compatible with multiple AGVs that have been investigated. This means that even if the used batteries do not last as long as a new one, then a replacement could be issued with ease, therefore using two or three used batteries instead of one new one. This decision will be justified providing that the AGV manufacturer will comply with the proposed plan.

The availability of these batteries is also a factor as Ford of Britain predicted that by 2029, they would have sold 60,000 Electric/Hybrid vehicles in the UK alone (see figure 20). This emphasises the massive potential of the battery project and the quest for second-life usage. Although these batteries will not be sent to BEP due to its closure by these dates, any findings from this project could be passed on to the innovation departments in other Ford plants if the usage of AGVs in Ford could be warranted.

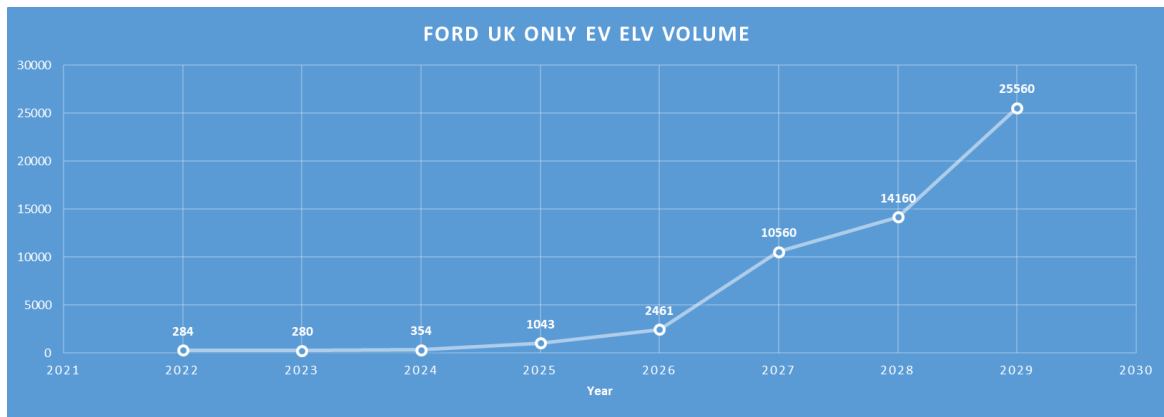


Figure 20 – Predicted Ford electric vehicle sales (Ford, 2019)

5.4.4 AGV Matrix

The following matrix of various AGVs from different manufacturers was created to aid with comparing the critical aspects of each product against one another to assist in the selection for the most suitable vehicle for the project. The details included in the matrix were comprised by the project champion as a result of conferring with multiple FMC engineers throughout Ford of Europe who been in contact with various AGV manufacturers for other potential projects (Del Portillo, 2020) (Moreton, 2019) (Spurling, 2020).

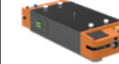
	KIVNON K11 MOUSE	CLEM CM3000	ASTI Bidibot	Myzer Smart Mause 2000	KUKA KMP 1500	OTTO 100	CLEM CM1200	MiR 500	KUKA KMR 200	MiR 200	OMRON LD90
AGV											
Length (mm)	2010	2266	2000	1200	2000	1810	2266	1350	1080	890	699
Width (mm)	500	420	500	400	800	1190	420	920	630	580	500
Height (mm)	333	250	230	250	470	351	250	320	700	352	383
Payload											
Payload (kg)	3000	3000	2000	1600	1500	1500	1200	500	200	200	90
Speed											
Max speed (m/s)	0.75	0.66	0.7	1.33	1	0.8	0.66	1.5	1	1.1	1.8
Batteries											
Battery	AGM	Lithium Ion	Lithium Ion	Lithium Ion	TBD	51.2VDC nominal 50A	Lithium Ion	Li-NMC, 24V, 40 Ah	TBD	Li-NMC, 24V, 40 Ah	72 Ah
Charging Time (h)	1	1	1	1	2	1.5	1	1	TBD	3	4
Working time (h)	8	8	8	8	8	8	8	8	TBD	9	15
Communication											
Type	Radio	WiFi	Radio + WiFi	Radio + WiFi	WiFi	WiFi (802.11 a/b/g/n/ac, 2.4GHz, 5 GHz)	WiFi	WiFi	WiFi	WiFi	WiFi
Guidance											
Type	Magnetic	Magnetic	Magnetic	Magnetic or SLAM	SLAM	SLAM	Magnetic	SLAM	SLAM	SLAM	SLAM
Scanner	Sick	Sick	Sick	Sick	Sick	Sick	Sick	Sick	Sick	Sick	Sick
Maintenance / year											
Service	National	Local	National	National	National	International	Local	Local	National	Local	Local
Cost											
Approx. Price (unit)	£22,230.00	£20,886.50	£20,681.00	£12,500.00	£76,630.00	£44,000.00	£18,620.00	£34,800.00	£97,900.00	£21,800.00	£26,000.00

Figure 21 – AGV Selection Matrix

5.5 SELECTION PROCESS

5.5.1 Phase 1 - Vehicle Criteria

During any selection phase of a project, determining the criteria that needs to be adhered to will help in narrowing down the selection by eliminating unnecessary candidates. Taking the concluded findings of exploring the navigation and battery aspects of the AGV, the candidates displayed in figure 21 could be reduced to the following by eliminating candidates that did not offer Lithium-Ion batteries or Visual and Laser guidance.

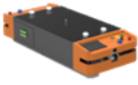
	Myzer Smart Mauser 2000	OTTO 100	MiR 500	MiR 200	OMRON LD90
AGV					
Length (mm)	1200	1810	1350	890	699
Width (mm)	400	1190	920	580	500
Height (mm)	250	351	320	352	383
Payload					
Payload (kg)	1600	1500	500	200	90
Speed					
Max speed (m/s)	1.33	0.8	1.5	1.1	1.8
Batteries					
Battery	Lithium Ion	51.2VDC nominal 50A	Li-NMC, 24V, 40 Ah	Li-NMC, 24V, 40 Ah	72 Ah
Charging Time (h)	1	1.5	1	3	4
Working time (h)	8	8	8	9	15
Communication					
Type	Radio + WiFi	WiFi (802.11 a/b/g/n/ac, 2.4GHz, 5 GHz)	WiFi	WiFi	WiFi
Guidance					
Type	Magnetic + Visual	SLAM	SLAM	SLAM	SLAM
Scanner	Sick	Sick	Sick	Sick	Sick
Maintenance / year					
Service	National	International	Local	Local	Local
Cost					
Approx. Price (unit)	£12,500.00	£44,000.00	£34,800.00	£21,800.00	£26,000.00

Figure 22 – Revised AGV Matrix

This section of the report discusses each category displayed in the revised AGV Matrix shown in figure 22. The relevance of each category was graded **Low**, **Medium** or **High** to aid for further analysing of candidates, to ensure that the most appropriate product is selected. This section includes information from FMC's Controls Hardware Specification sheet regarding Ford's AGV policies (Kekedjian, 2017). The full document cannot be included in the report appendix due to FMC data protection policies, however, the relevant fragments have been included where necessary.

5.5.1.1 Size

The size of the vehicle will not have a significant influence on the selection. Although a smaller vehicle would be better for storage purposes, the AGVs for selection will be graded on the criteria of higher relevance first.

Relevance - Low

5.5.1.2 Payload

The operational requirements for this project stated that vehicles would be subjected to a payload of 50-120kg, depending on how many tools are required. Only one of the AGVs in the matrix does not meet this requirement with the remainder exceeding it by a great deal. When selecting the product for this project, the AGVs will not be prioritised for their larger payload size as it is likely that their manufacturers would have focused their development on bearing these large loads, as opposed to carrying out the more precise manoeuvres required for this project.

Relevance - Low

5.5.1.3 Speed

“7.1 Travel performance shall be in accordance with ANSI B56.5 and shall have the following travel speed restrictions.

7.1.1 Maximum speed on level concrete when loaded, 3.0 miles per hour (264 FPM) (4.8 km/h or 1.33 m/s)

7.1.2 Maximum speed on level concrete when empty, 3.5 miles per hour (308 FPM) (5.6 km/h or 1.56 m/s)”

Vehicle speed will be considered but will not be a main deciding point. Providing that the AGV can travel within a reasonable speed that is below the limits addressed from the specification sheet, then it will likely be accepted.

Relevance - Medium

5.5.1.4 Communication

“5.1.4 The AGV Wi-Fi system shall utilize 3 channels (157, 161 and 165) in the 5.0 GHz bandwidth, unless otherwise directed by the IT Global WLAN group. Reference Siemens Scalance W-784-1xx / W-74x-1 Operating instructions for National approvals and channel allocation for the destination country and required antenna hardware variations for each country.”

The selected product must support a Wi-Fi compatible communication system.

Relevance - High

5.5.1.5 Maintenance

Ideally, a local manufacturer would be convenient as the purchase of any external parts and any repairs within the warranty would be made easier. However, this just preference and will not be weighted highly when deciding on the best product.

Relevance - Low

5.5.1.6 Cost

The cost of the AGV will likely be the final selling point as the project will be subject to Ford's payback analysis technique; Time Adjusted Rate of Return (TARR) of the initial investment within the first six months of operation. The TARR calculates the cost of implementing the project against both the cost savings and compared to the wages of the operator(s) that it will be replaced, therefore, the cheaper the AGV, the faster the rate of return.

Relevance - High

5.5.2 Phase 2 – Pugh Matrix

A Pugh matrix is a tool that can be implemented to compare multiple candidates during a selection process to determine which one meets a set of criteria the most (Burge, 2009). For the next stage of the selection process, this tool was used to score each candidate accordingly on each of the sections discussed in the vehicle criteria. Each section was scored out of five, with the relevance of each section being weighted as; Low: x1, Medium: x2 and High: x3, to ensure that the scoring reflects the importance of each aspect (see Figure 23).

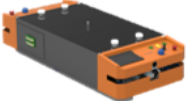
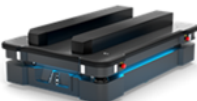
		Myzer Smart Mause 2000	OTTO 100	MiR 500	MiR 200	OMRON LD90
Feature	Weighting					
Size	1	4	2	3	5	5
Payload	1	3	3	1	1	1
Speed	2	4	1	4	3	5
Communication	3	5	5	5	5	5
Maintenance	1	4	2	5	5	5
Cost	3	5	1	2	3	3
Total Score		49	27	38	41	45

Figure 23 – Pugh Matrix criteria scoring system

5.5.3 Phase 3 – Reviewing Scores

On reviewing the Pugh Matrix displayed in figure 23, it is clear that the Myzer Smart Mause 2000 is the best option for the project regarding the scores. To safeguard that this AGV was the best candidate for the project and not just an anomaly in the scoring system, each category was reviewed and revised further.

The Myzer product is not the fastest of the remaining candidates, but it is smaller, which will be of greater convenience for storage purposes. Despite its smaller dimensions, the Smart Mause has a large payload allowance. Although this is more than the operational requirements, it leaves the possibility of utilising the AGV for other purposes as well as tool delivery. Finally, the price of the Smart Mause is the cheapest option which will fare better with management regarding the prospect of the project being approved and funded.

5.6 MYZER SMART MAUSE 2000

The Myzer Smart Mause 2000 is the AGV that scored the highest out of the many products that were considered during the selection stage. Once this AGV variant was confirmed to be the appropriate choice going forward, a meeting was arranged by Phil Moreton with Myzer Sales Representative Guy Glover to discuss the capabilities of the product regarding the project.



Figure 24 – Myzer Smart Mause 2000 AGV

This product comes equipped with a vast number of safety sensors, beacons and a horn that can be utilised when needed to enhance the safety of the vehicle. The Smart Mause is also flexible as it can transport loads in two ways; towing and lifting. The body of the unit is equipped with a lifting mechanism that can raise several inches to transfer loads, acting as a unit load carrier. It also has a computer-controlled tow hook that can attach and detach trailers on demand, acting as a towing vehicle.

5.6.1 Battery Project

As previously discussed in the report, the ET department is researching a separate project that aims to utilise used Electric Vehicle (EV) lithium-based batteries for second-life purposes. One of the reasons that the Myzer AGV was selected due to its compatibility with Lithium-Ion batteries. This could be a key factor for reducing the cost and practicality of the whole AGV project, while also contributing to a different project that is being worked on by the ET department. This section of the report focuses on the possibility of using these batteries for the project solution.

This surplus of batteries could hugely benefit this project as it was discovered in the meeting between the Project Team and Glover (2019) that their AGV product used two 48V MHEV Type C Lithium-Ion batteries. As there were 16 of these included in the ET departments 28 battery collection, the question was put forth to Glover (2019) regarding the compatibility of these used batteries with the available Myzer product. Glover (2019) went on to confirm that these batteries would be acceptable to use with the Smart Mause, adding that Myzer were willing to provide the AGVs without the batteries which would have cost £2000 each, resulting in a potential cost saving of £4000 per unit purchased.

5.6.2 Mapping System

It was explained by Glover (2019) that Myzer uses a Simultaneous Localization and Mapping (SLAM) for their AGV systems to map out the environment that the AGV will be commuting through regularly. This system uses a combination of SLAM technology and aerial cameras which essentially allow the AGV to see precisely what is in front of it at all times. This technology works as a pair, as the aerial camera system provides the AGV with a rough route map. The AGV can then travel this route, mapping out every small detail like pillars, walls and barriers to give a far more detailed picture. The aerial cameras will remain in place and feedback any changes to the system such as vehicles, people, crates or any other obstacles. Figures 25 shows an example of how the onboard computer pairs the technology, allowing it to 'see' any obstacles and prevent a collision with the AGV, slowing down to a complete stop if required. The AGV can also divert its path slightly to avoid stationary obstacles, with Figure 26 showing how the software takes action to avoid the obstacle by redirecting the travel path of the AGV.

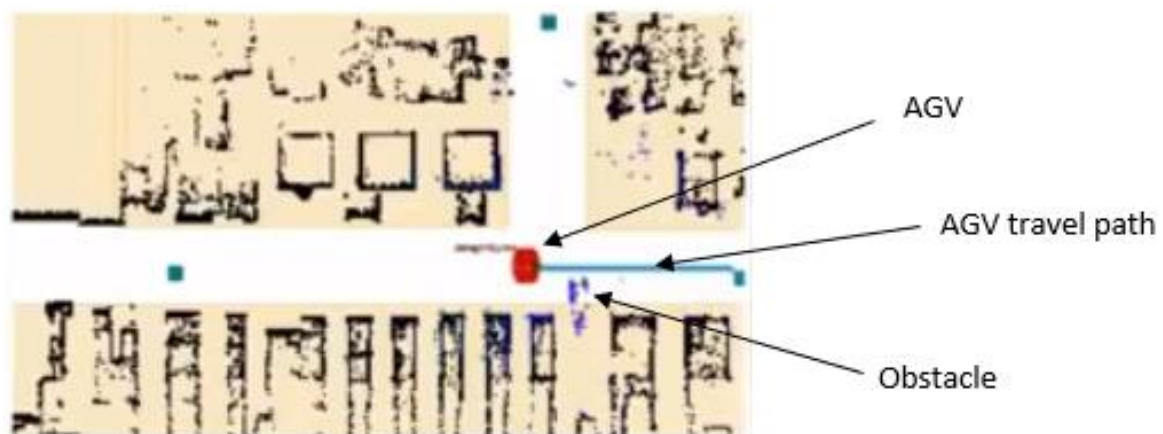


Figure 25 – Mapping software showing the AGV approaching an obstacle

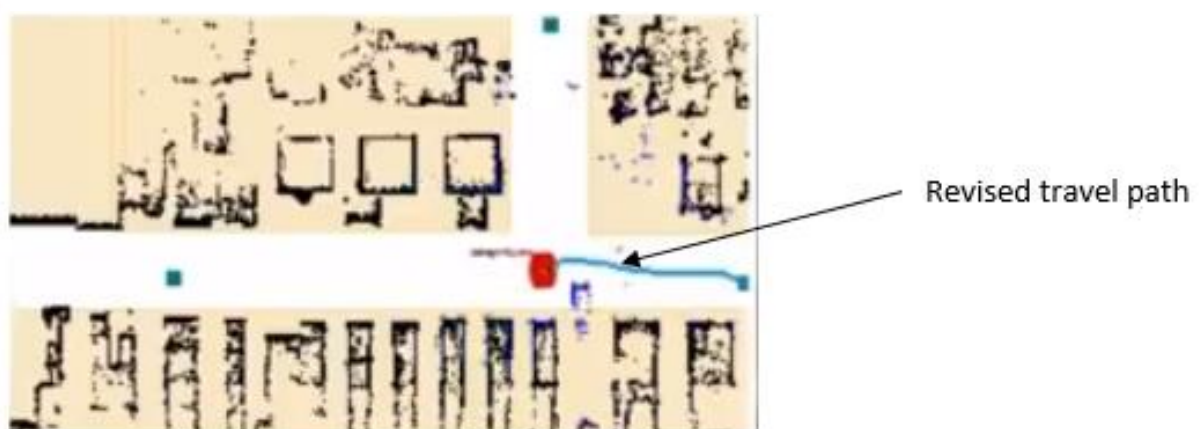


Figure 26 – Mapping software showing a revised travel path to avoid obstacle

5.6.2.1 Aerial Camera Locations

The line layout and dimensions were issued to Glover (2019) to determine the number and positioning of the aerial cameras required for the AGVS. It was then decided that nine cameras were needed in the positions marked with a red cross in figure 27.

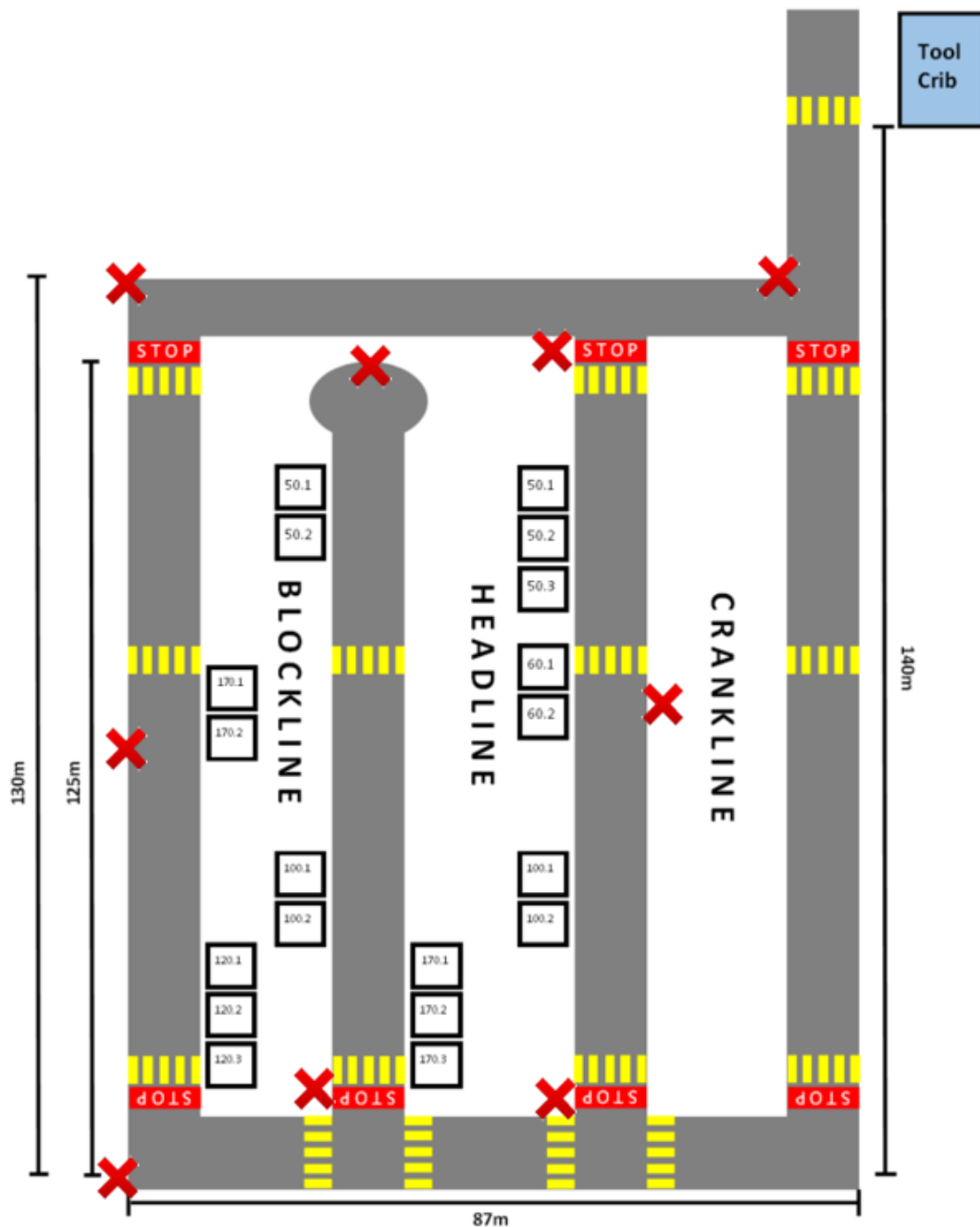
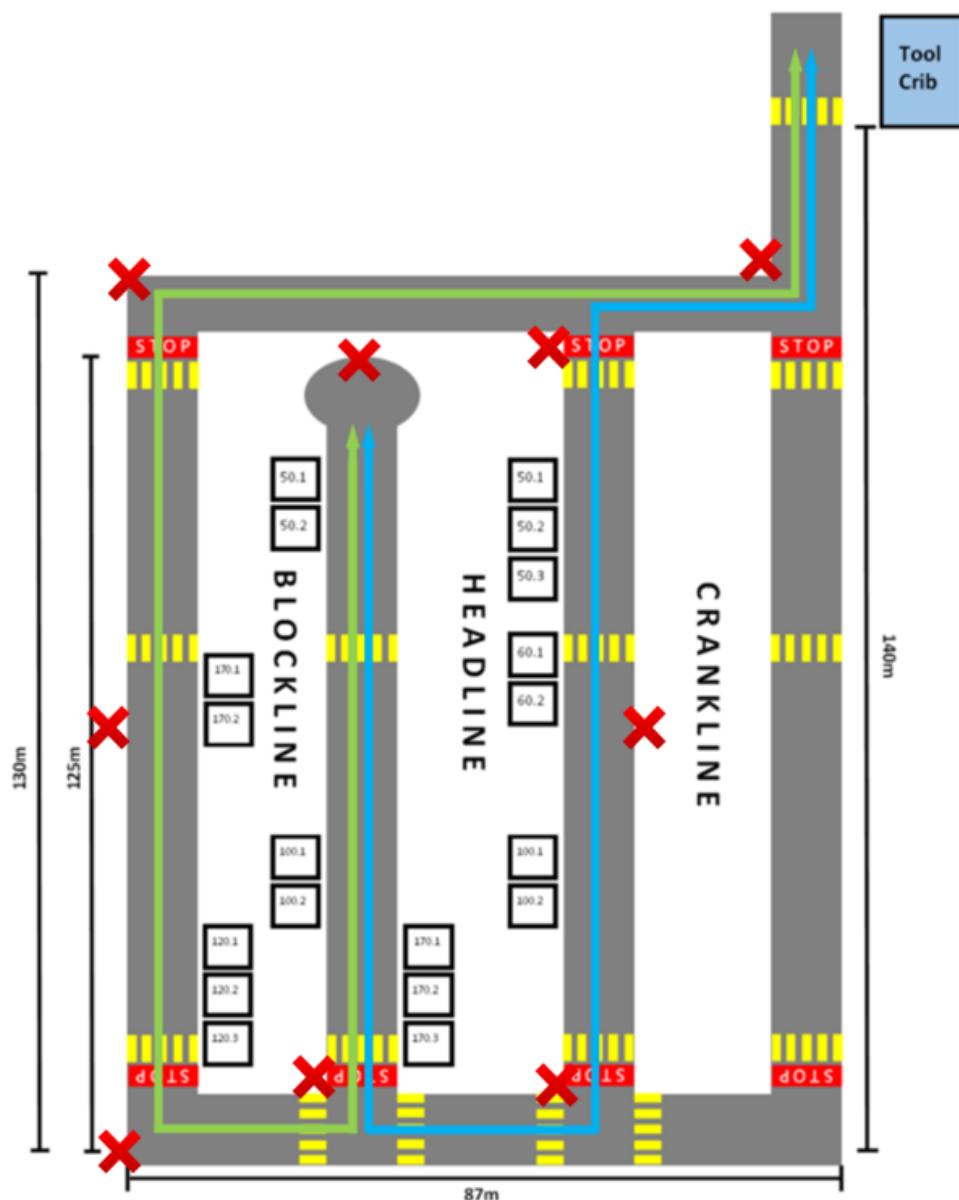


Figure 27 – Aerial camera positioning

5.6.3 Path Switch Method

Groover (2015) expressed that setting up multiple route paths for the same AGV system can be beneficial for the efficiency of deliveries. The path selection will often depend on the destination of the delivery but can also be used as preparation for congestion or blockages. An algorithm can be installed within the mapping software that uses the velocity of obstacles, such as crowds of people or vehicles, along each pathway to determine the quickest route (Dharmasiri, et al., 2019).

Increasing the number of delivery paths for an AGV has proven to be an effective strategy throughout manufacturing (Bilge & Tanchoco, 1997), therefore, the project team opted to use this approach for this AGV system. Figure 28 shows two pathways that could be utilised for the delivery of tools. These pathways were carefully considered by the project team, avoiding the road parallel to the crank line that is used regularly as a through road for MEWPs to the Sigma Module 3 line located next to Dragon.



5.6.4 Cost Analysis

The purpose of the Explore phase of this report was to explore the technologies surrounding an AGV system so that a comparison could be made to the secondary solution of adding more men to the area. Therefore, before commencing to the developing stage of the project, cost analysis must be conducted to ensure that the AGV project is more beneficial than the current tool change process and adding more tool setters to the area. The project team enquired to Glover (2019) about a price quote for the whole project. As the number of vehicles required for the project had not been decided at this point, the team asked for separate quotes for a single AGV system and a double AGV system.

Item	Cost	Quantity	Total
Smart Mause AGV	£8,500.00	1	£8,500.00
Charging Points Power Drops	£1,600.00	1	£1,600.00
Capture Box Ethernet Drops	£1,600.00	1	£1,600.00
Capture Box Power Drops	£1,100.00	1	£1,100.00
Wheels - locking mechanism	£900.00	1	£900.00
Custom Trailers	£350.00	10	£3,500.00
Docking Station	£1,200.00	2	£2,400.00
SMART Integration	£2,700.00	1	£2,700.00
Capture System	£4,500.00	1	£4,500.00
SLAM Software	£1,200.00	1	£1,200.00
Aerial Cameras	£450.00	9	£4,050.00
Total Cost of Project			£32,050.00

Figure 29 – Price quote for a single unit AGV systems (Glover, 2019)

Item	Cost	Quantity	Total
Smart Mause AGV	£8,500.00	2	£17,000.00
Charging Points Power Drops	£1,600.00	1	£1,600.00
Capture Box Ethernet Drops	£1,600.00	1	£1,600.00
Capture Box Power Drops	£1,100.00	1	£1,100.00
Wheels - locking mechanism	£900.00	2	£1,800.00
Custom Trailers	£350.00	10	£3,500.00
Docking Station	£1,200.00	2	£2,400.00
SMART Integration	£2,700.00	1	£2,700.00
Capture System	£4,500.00	1	£4,500.00
SLAM Software	£1,200.00	1	£1,200.00
Aerial Cameras	£450.00	9	£4,050.00
Total Cost of Project			£41,450.00

Figure 30 – Price quote for a two unit AGV system (Glover, 2019)

5.6.4.1 Time Adjusted Rate of Return (TARR)

The technique used by FMC engineers to determine the payback rate of a project in comparison to an operator is Time Adjusted Rate of Return (TARR). This method is used by engineers to compare the cost of a project against employee wages over six months to see what the best outcome is. The TARR percentage determines how much a project will pay itself back in comparison to additional labour, with the goal being for it to TARR 100% and upwards (Moreton, 2019). Given that the cost of a tool setter, including pension for a year, is £72,000, the 6-month value will be £36,000. Dragon machining operates a 4-shift pattern, meaning that a tool setter will need to be assigned to each shift, totalling £144,000.

Therefore:

$$\text{TARR} = \text{Wages} \div \text{Cost of Project} \times 100\%$$

$$\text{1 AGVS TARR} = £144,000 \div £32,050 \times 100\%$$

$$\text{TARR 1 AGVS} = 449.3\%$$

$$\text{2 AGVS TARR} = £144,000 \div £41,450 \times 100\%$$

$$\text{2 AGVS TARR} = 347.4\%$$

It can be seen from the above equation that the TARR of an AGV system consisting of both one and two AGVs comfortably pays itself back multiple times over when compared to the cost of four tool setters over six months.

It was calculated in the Measure stage of the project that the annual cost of wages lost due to the wastes present with the current process, excluding any costs of lost business as a result of downtime was £35,566.40. When reviewing the quotes obtained from Glover (2019), it can be observed that the total cost of the AGV project is less than the cost of the wastes, meaning that the cost of wasted wages alone could almost cover the cost of the project. Considering that there will also be periods of downtime present if the current process remains, costing Ford £82,000 an hour, then the AGV delivery system is warranted.

In terms of cost and payback analysis, the AGV system is far superior to the current tool change process and the method of employing more tool setters. Not only is the AGV system cheaper over the first six months, but it is also a one-off payment.

6.0 DEVELOP: DETAILED DESIGN

6.1 ACTION PLAN

The development stage of a project aims to take the findings of the research conducted in the Explore stage and develop a design that best adheres to the needs of the customer (George, et al., 2005). To achieve a final design that can be implemented with minimal drawbacks, an action plan was created with each task undergoing thorough brainstorming to ensure that every aspect of the new AGV tool delivery system had been carefully considered.

Table 13 – Development Action Plan

Action Plan					
Task	What	How	Who	Why	When
Conceptual Design	Determine the number of vehicles required, as well as a preliminary process	Using the information gathered in the Explore phase	Project Champion	To provide an outline of the process to give to management for review before developing further	March - April 2020
Cost Reduction	Review the concept design and brainstorm ways to reduce costs	Consider resources available in-house that could be utilised	Project Champion	To reduce the cost of the project	March - April 2020
Critically Appraise	Thoroughly review the conceptual design and make modifications to strengthen the process	Using DFMEA and Poka-Yoke	Project Champion	To eliminate any potential failure modes in the final design	March - April 2020
Final Design	Construct a final design that is ready to be put forward for future implementation	Combining the findings of the development stage	Project Champion	To aid with the implementation in other FMC engine plants	March - April 2020

6.2 CONCEPTUAL DESIGN

The first stage in developing the new tool delivery process is the conceptual design phase. This stage is critical as it allows the project team to brainstorm ideas based on the findings of the Explore phase. The concept of this design is to produce a base model of the new delivery system that can be shown to management, in order for them to review (Linton, 2019). Thorough brainstorming and developing will commence once the base model is approved, so that time and resources are not expended in the event that management does not approve of the design.

6.2.1 AGV Journey Times

Before a concept design can be created, further research was required regarding the duration that the AGV will be operating each shift. This information is essential and will be required at a later stage in the project to determine the number of vehicles needed for the AGV system.

From the data displayed in the From-To chart in chapter 5 of the report, as well as the speed that the Myzer Smart Mause can travel (1.33 m/s), the duration of a tool delivery to each machine OP could be calculated. The results have been displayed in tables 14 and 15.

Table 14 –AGV journey time matrix

AGV Journey Times (seconds)		
OP	Head	Block
50	$612 \div 1.33$ = 460	$106 \div 1.33$ = 80
60	X	$126 \div 1.33$ = 95
100	$452 \div 1.33$ = 340	$276 \div 1.33$ = 208
120	$438 \div 1.33$ = 337	X
170	$318 \div 1.33$ = 239	$422 \div 1.33$ = 420

Table 15 – AGV journey times converted to minutes

AGV Journey Times (mins)		
OP	Head	Block
50	7.7	1.3
60	X	1.6
100	5.7	3.5
120	5.6	X
170	4	7

To account for the loading and unloading times, as well as any potential delays as a result of congestion on the factory roads, the project team decided to include an additional minute to each delivery. This decision was made to maintain continuity between the factors that influence the tool change process addressed in the data collection stage and the new AGV design to avoid biases. This means that a total of 20 minutes will be added to the AGV delivery times. Using the values from tables 14 and 15, the time taken for the Myzer AGV to complete the frequent scenario of 20 tool changes per shift was estimated around 93 minutes (see table 16).

Table 16 – Estimated AGV delivery times per shift

AGV Delivery Matrix		
OP	Head	Block
50	7.7×2 = 15.4	1.3×2 = 2.6
60	X	1.6×2 = 3.2
100	5.7×2 = 11.4	3.5×2 = 7
120	5.6×6 = 11.2	X
170	4×2 = 8	7×2 = 14
Total (mins)	46	26.8
	72.8 (+ 20) = 92.8	
Total (Hrs)	1.55	

Depending on how the old tools are returned to the tool crib, it is possible that this value could be doubled. An idea discussed during brainstorming was to implement a timer on the AGV that would instruct it to return to a station to collect the old tool 30 minutes after it was delivered, giving the operator on that machine plenty of time to have the old tool ready to collect. A second trip to recover the old tool would result in the estimated journey time of 1.55 hours in table 16 being doubled, becoming 3.1 hours.

6.2.3 Determining Number of Vehicles

The payback analysis of the AGV system using both one and two vehicles both had TARR scores drastically exceeding the 100% target. Therefore, the cost difference between the two will not be a deciding factor to determine the number of vehicles to opt for. The selection was determined by carefully considering the pros and cons of each option.

Given the findings addressed in this report regarding the operational requirements and estimated AGV delivery times per shift, the use of calculations or simulation methods discussed in the literature review were deemed to be excessive for this project. Considering that the Myzer AGV should only be required for an average of 3.1 hours per shift, an assumption of one AGV unit being required would seem reasonable. However, determining the fleet size needed for this project is not that simple as multiple factors need to be taken into account.

6.2.3.1 Considerations

Firstly, when preparing a conceptual design, the worst-case scenario should always be considered. A reasonable method of accounting for this would be to double the amount of time that the AGV is required to operate. This will ensure that any unforeseen factors have been considered, e.g. a very high TCF day with a high volume of traffic on the roads. This gives a maximum operational requirement of 6.2 hours per shift.

The battery life of Myzers Smart Mause 2000 was quoted to last 8 hours with a new lithium-ion battery. Using a second life battery would change this figure as the batteries available for this project were found to have 75% life left. This now equates to around 6 hours of battery life per charge, which would allow an AGV to operate for half a shift. This means that a single AGV would not be able to work under the conditions given in the scenario regarding a very high TCF shift. Also, second-life batteries are more susceptible to oxidation which will contribute to longer charge times and reduce the overall performance.

6.2.3.2 Conclusion

Taking the points addressed in the previous section into consideration, it is clear that having just one AGV in the system would be unacceptable. Therefore, the decision to include two AGVs in the system was debated and justified as follows.

Firstly, the use of two AGVs would speed up the tool delivery system, as the vehicles could operate simultaneously if required. This would reduce any wait times and ensure that tools are delivered to machines within a matter of minutes after the low limit warning becomes active, providing that tool setters are alert.

Furthermore, there is far more flexibility regarding breakdowns with two units as if one breaks down or requires charging; then the tool deliveries can still be carried out at 50% capacity. The use of two vehicles would also half the workload being put on each unit, meaning the lifetime of second-life batteries being used will be prolonged as they will be used less. This will also reduce the wear and tear subjected to each unit by 50%, which should, in theory, prolong the life of each unit and increase the time between breakdowns or failures.

6.3.1 Cost Reductions

The decision was made by the project team to briefly cease the development of the new tool delivery process so that the process could be examined closer in an attempt to reduce costs. Doing so would increase the TARR of the project, as well as reduce its payback time.

6.3.1.1 Estates Department

The task of installing the AGV power and ethernet drops could be assigned to the BEP electrical estates department. The department have installed many personnel vehicle charging points and ethernet drops for supervisor's offices and employee computers located on the production lines, so there should be no issues with doing the same for the AGV station.

If these tasks are absorbed by the electrical estates department, then an initial payment of £4300 will be saved that would have been paid to Myzer to install two power drops and an ethernet drop. The components will still have to be purchased from Myzer costing £1300 (Glover, 2019), equating to a cost saving of £3000.

6.3.1.2 Tinsmith

Figure 31 shows an FMC standard tool trolley that is used on machining lines in BEP and other Ford plants around the world to aid with the transportation of multiple tools. A small modification could be made to these trolleys in the form of a towing eye (see figure 32) that would make it compatible to be attached to the AGV as a trailer. The idea of the towing eye modification was discussed with the BEP tinsmith, who supported the idea, explained that he had worked on a similar job in the past and that the towing eyes could be manufactured and fitted by any trained tinsmith with ease (Jenkins, 2020). This would eliminate the need to purchase trailers from Myzer as these trailers are easily accessible, resulting in a further cost saving of £3500.

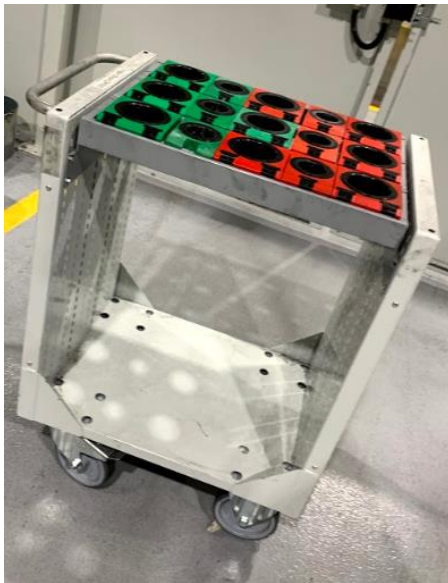


Figure 32 – Tool trolley



Figure 31 – Towing Eye modification

Total Cost Saving

$$= \text{£}3,000 + \text{£}3,500$$

$$= \text{£}6,500$$

New Cost of Project

$$= \text{£}41,450 - \text{£}6,500$$

$$= \text{£}34,950$$

$$\text{TARR} = \text{£}144,000 \div \text{£}34,950 \times 100\%$$

$$\text{TARR} = 412\%$$

6.2.4 Loading and Unloading

Drop-off /Collection Points

The Smart Mause AGV can attach and detach trailers without any human interaction, providing that it knows the exact location of the trailer. The coordinates of this location can then be programmed into the AGV software and identified as a pickup/drop-off point. These trolley bays could be added to the line using the same concept as swarf bin bays (see figure 34) to aid with the positioning of trolleys. These locations can be programmed into the AGV software, corresponding to each OP. Figure 35 shows a diagram explaining the drop station, showing the location of the markings that can be painted onto the floor to determine where the trolley must be to locate for a secure pickup. Multiple drop off points can be assigned with the use of markings relevant to each OP, forming drop stations specific to each machine.



Figure 33 – Potential tool trolley drop off bays

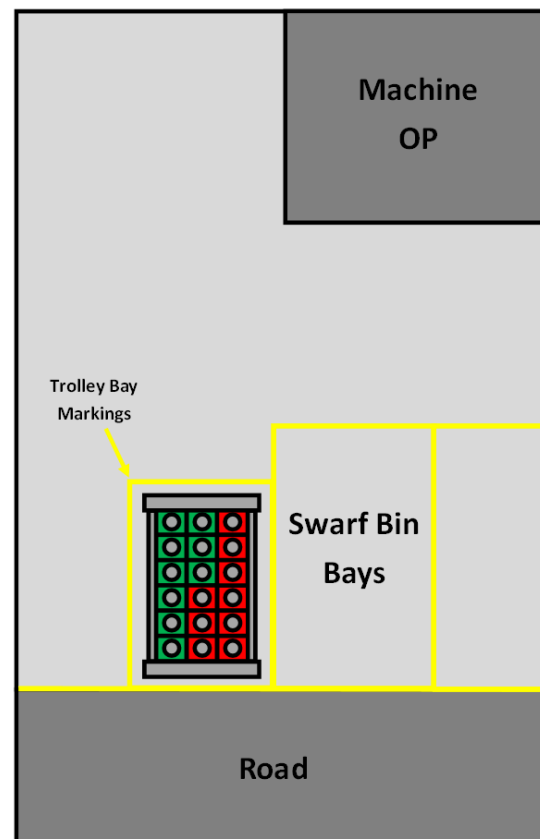


Figure 34 – Trolley bay diagram

Loading

Tool setters can insert new tools into the green section of a tool trolley that is attached to the AGV (see figure 35) and select a drop station via a Human-Machine Interface (HMI) touch-screen integrated with the AGV software. Figure 36 shows a possible HMI layout to aid with a quick and easy selection for tool setters when distributing tools through the AGV. Operators can then place used tools into the red section of the tool trolley ready for collection.



Figure 35 – Colour coordinated tool holsters (Green – New, Red – Used)

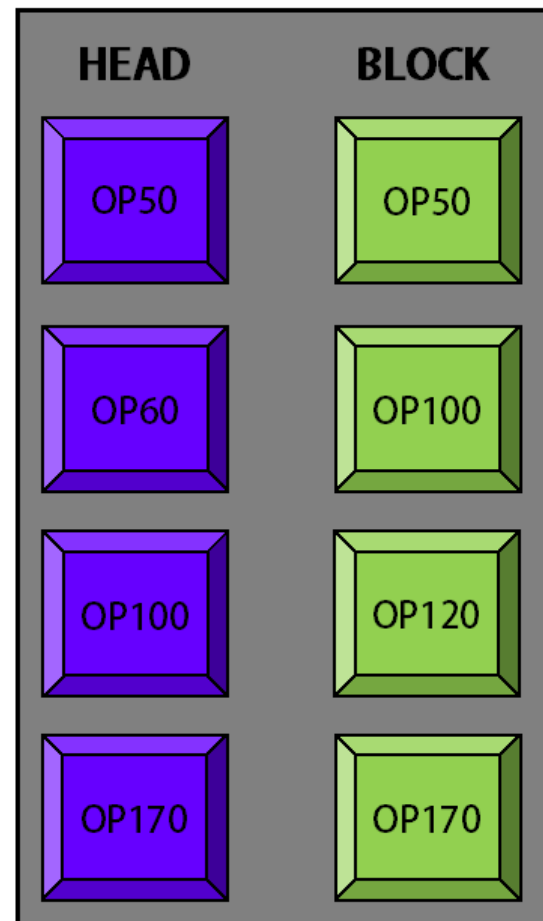


Figure 36 – Dropoff selection HMI screen

6.3 CONCEPTUAL DESIGN –TOOL DELIVERY PROCESS

The following process was designed by the Project Champion

- Tool setters are notified of any upcoming tool changes via tool life monitoring software integrated with each machine on the line, allowing them to prepare tools for delivery.
- When tool life is approaching the low limit, the tool life low limit warning light comes on, indicating to the operator that a tool change is soon required.
- Tool setter loads tool(s) into the tool trailer attached to the AGV and inputs a destination (OP number).
- The AGV follows the relevant route path to travel to a drop off station that corresponds to the OP requiring the tool change, detaches the trailer and returns to the tool crib.
- The operator walks to the drop of station 5-10 meters away from the machines to retrieve the tool.
- Operator conducts tool change.
- Operator inserts expired tool(s) back onto the same trolley to await collection by the AGV.
- A 30-minute timer begins through the AGV software, when this expires the AGV will commence with the collection of the expired tool(s).
- AGV retrieves trolley containing the old tool(s) from the exact spot it dropped off and returns it to the tool crib.
- Tool setters collect the old tool(s) from the trolley so the holster(s) can be reused.

6.3.1 Appraising New Process

If the conceptual design were to be implemented on Dragon, the waiting and unnecessary movement wastes discussed in the measure phase should be eliminated. This being as there is now no handover between the tool setter and operator, meaning that the tool should be sent out as soon as the tool setter receives a low life notification via the monitoring software. Delays could occur if the tool setters did not see the information on the screen, but even then, a wait will be unlikely due to the low life warning buffer.

The central aspect of the new design is that the transportation times present with the tool change have been reduced from approximately 9 minutes per tool change to around 30 seconds. To put this into perspective, the total time waste due to tool changes (not including wait times) was calculated in the Measure phase to be **97004** minutes per year as a result of **9542** tool changes, costing Ford around £35,000 per year in wages. This value will drop to approximately **4771** minutes (9542×0.5) per year as a result of the new AGV delivery system, costing Ford just £1,750 per year in wages.

This is the main benefit of any AGV system as nearly all of the transportation waste is absorbed by the vehicle, requiring minimum human interaction, enabling operators to utilise their time elsewhere. Although there is technically more transport waste present with this process, it will not affect production or operator productivity.

6.4 REVIEWING CONCEPTUAL DESIGN

With management satisfied with the conceptual design, the project could commence to the next task relevant to development. The next step involved thoroughly reviewing the conceptual design to eliminate any potential modes of failure that could contribute to problems once implemented. For this stage of the project, a meeting between the members of the project team, tool setters and team leaders to review the conceptual design and address any concerns, improvements or modifications regarding the process (Cresswell, 2020) (Moreton, 2020) (Williams, 2020).

The results of this meeting flagged several possible concerns regarding potential modes of failure in a system.

6.4.1 Design Failure Mode and Effect Analysis (DFMEA)

As discussed in the literature review, FMEA is a tool used by engineers to locate any potential problems with a new system or design by identifying the possible modes of failure that are present with it (Anleitner, 2011).

To help review the conceptual design and rid it of any probable causes of failure, a Design FMEA was created to identify any potential failure modes from the topic raised in the recent team meeting that may cause issues once the new delivery system is implemented. Fail-safe methods were then added to the design using a Poka-Yoke approach, essentially ‘mistake-proofing’ the design to eliminate any potential failure modes that may be present once implemented (Kanbanize, 2019).

Poka-Yoke is a continuous improvement technique that is used in lean manufacturing to fine-tune any improvements and process designs (Schonberger, 2008). This approach was selected to reduce the need to rely on a trial and error format during implementation by aiming to eliminate any possible means of failure the first time around.

Table 17 – Design FMEA table

Input	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Occurrence	Current Controls	Detection	RPN
AGV Tool Delivery System	AGV cannot locate tool trolleys for pick-up	Trolley is not returned to tool crib	3	Trolley has been moved and not placed in the precise pick up spot	6	None	4	72
AGV Tool Delivery System	Collisions with pedestrians/ vehicles	Injury to pedestrian	8	Pedestrian crossing without due care and/or attention	3	None	4	96
		Damage to vehicle	6	The small dimensions of the AGV will make it hard to see for vehicle drivers around sharp corners	5		6	180
		Severe damage to AGV	7	Driving without due care and/or attention	5		6	210
AGV Tool Delivery System	Trolley distribution	Tool crib expends all tool trolleys	3	Congestion due to the 30-minute timers	5	None	4	60

6.4.2 Recommended Actions

To overcome some of the issues present with the current system and reduce the RPN value of some of the potential failure modes, recommended action was required. The following section consists of possible solutions constructed by the project champion, using a poka-yoke fail-safe approach, to present to the project team for their approval. These actions can then be inserted back into the FMEA table as control measures for each failure mode addressed in Table 17 to reduce the RPN.

6.4.2.1 Trailer positioning

If the Smart Mouse was to be positioned underneath the tool trolley, it could raise several inches and transport the trolley in a unit load carrier manner (see figure 37). This would allow the tool trolleys to be utilised without requiring a tinsmith to add towing eyes to each trolley. This modification to the system would also increase the reliability of the trolley remaining in the same spot during drop-offs and pickups.

However, for larger tools, operators will be inclined to transport tools to their machines using the trolleys. This then creates a margin for error with collection if trolleys are not placed in the exact spot they were dropped off. To prevent this, a small barrier, raised several inches, could be bolted or glued in position to secure the trolley to act as a stop for the wheels to prevent rolling, with a gap leading into the road to allow for the AGV to drive in and out (see figure 38).



Figure 37 – New pick up position

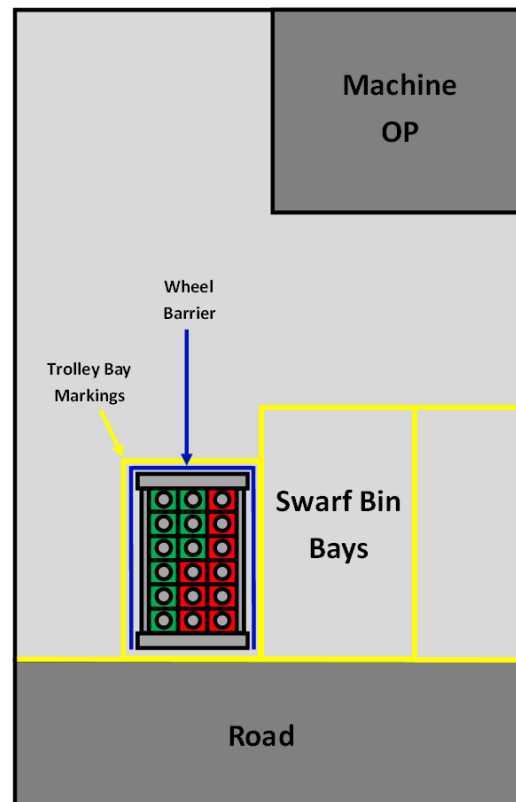


Figure 38 - Trolley bay diagram including wheel locator barrier

6.4.2.2 Collisions with pedestrians/vehicles

This is the main area of concern with the DFMEA table as the RPN is high. Several actions can be taken to reduce the probability of the AGV colliding with pedestrians or other vehicles. The Myzer Smart Mause 2000 comes equipped with state-of-the-art sensors and brakes to bring the unit to a stop if its pathway is impeded, meaning that a collision with a pedestrian is improbable. The problem with collisions lies more in the hands of vehicle drivers in plant, as if they are not alert to their surroundings and the approaching AGV, then they could still collide with the AGV when it is stationary.

Considering that the Smart Mause comes equipped with a warning horn that can be triggered at any point during a route via the computer software (Glover, 2019), this feature could be utilised to prevent this type of hazard from occurring. Once the journey has been mapped out using the SLAM software, specific areas of the route in which the horn will be activated. By programming the AGV to activate the horn as it is approaching any sharp bends, junctions and pedestrian crossings, the vehicle would be more noticeable for anyone walking or driving in its path, making it more detectable. The AGV can also be programmed to reduce its speed in these selected areas, further enhancing the overall safety of the vehicle and those working around it.

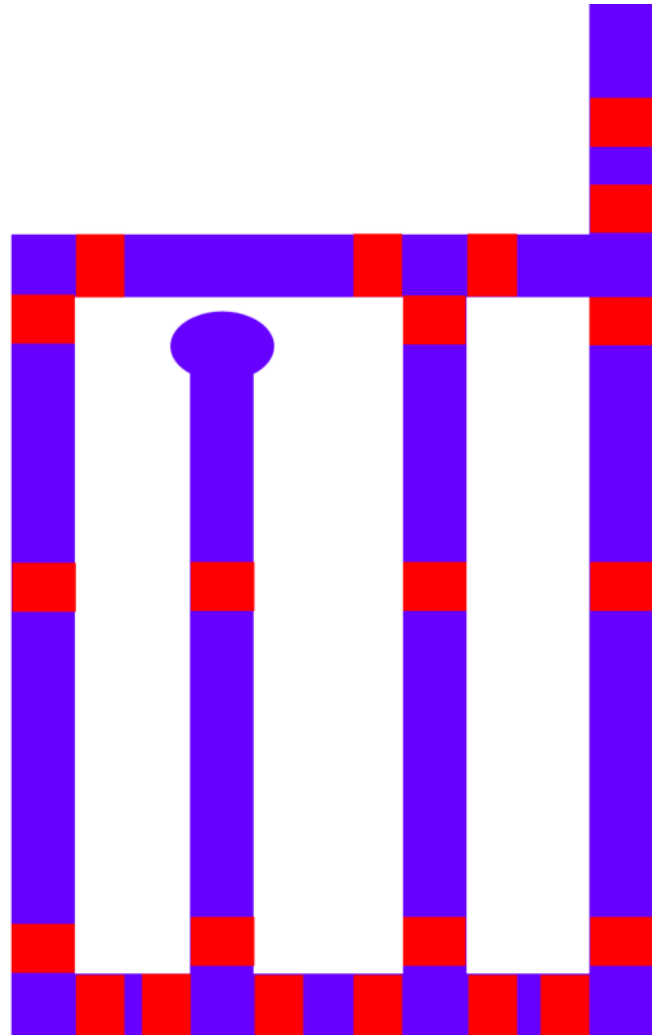


Figure 39 – Caution Zones displayed on the Dragon Machining layout

Figure 39 shows the areas in which these caution zones could be assigned to ensure the safest possible journey for the AGV and people working in the area. The blue area represents the journey route, with the red zones determining the areas best suited for slower speeds and a warning horn.

6.4.2.3 Call for Collection

The method of collecting the used tool in the conceptual design involved programming a timer to instruct the AGV to return to a delivery station 30-minutes after a delivery to collect the used tool. However, this method is not stable as it involves anticipating that the tool change has been conducted and could contribute to waiting waste if all trolleys have been expended.

Figure 40 shows a remote device used in BEP to communicate with the Material Planning and Logistics (MP&L) Department when parts are low and require restocking to call for new parts. When pressed, this device sends a signal to the MP&L computer system, notifying staff that a specific part is needed in a particular area. This remote device could be integrated with the AGV computer system to allow operators to call for the collection of the used tool once they have completed the tool change. This signal would then trigger the AGV to return to that drop station when available, as opposed to waiting 30-minutes. This method would promote a constant flow of tool trolleys to ensure that there are no wait times present with this new process. If this device is pressed while the AGV is already assigned to a task, then the software will decide whether the best option is to queue the task on the AGV, or simply send out the second vehicle.



Figure 40 – Part calling remote device

6.4.3 Revised FMEA

Table 18 – FMEA table using control measures

Input	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Occurrence	Current Controls	Detection	RPN
AGV Tool Delivery System	AGV cannot locate tool trolleys for pick-up	Trolley is not returned to tool crib	3	Trolley has been moved and not placed in the precise pick up spot	3	AGV picks up trolley instead of towing. Drops in a secure zone to prevent rolling.	3	27
AGV Tool Delivery System	Collisions with pedestrians/ vehicles	Injury to pedestrian	8	Pedestrian crossing without due care and/or attention	2	Implementing 'Caution Zones' where the AGV will slow down and activate a horn	2	32
		Damage to vehicle	6	The small dimensions of the AGV will make it hard to see for vehicle drivers around sharp corners	2		2	24
		Severe damage to AGV	7	Driving without due care and/or attention	2		2	28
AGV Tool Delivery System	Trolley distribution	Trolley is not returned to tool crib	3	Congestion due to the 30-minute timers	2	Call for part devices	2	12

Table 18 shows how implementing the actions discussed in the previous section as control measures will drastically reduce the RPN of each potential failure mode. When comparing Table 17 and 18, it can be seen that the severity of each failure mode remains the same. The purpose of the measures taken was to lower the RPN by reducing the likelihood of that problem occurring. Increasing the chances of the problem being detected also reduces the RPN, this is most apparent for preventing collisions with pedestrians and vehicles as implementing the warning horn will significantly increase the chance of someone driving without due care and attention noticing the AGV.

6.5 FINAL DESIGN - TOOL DELIVERY PROCESS

The following process lists the steps of the final design process that will be used as part of the AGV tool delivery system. This final design is a revised version of the conceptual process displayed at the start of this chapter of the report, including several modifications to account for the changes made during the critical appraisal of the design.

- **Tool setters are notified of any upcoming tool changes via tool life monitoring software integrated with each machine on the line, allowing them to prepare tools for delivery.**
- **When tool life is approaching the low limit, the tool life low limit warning light comes on, indicating to the operator that a tool change is soon required.**
- **Tool setter loads tool(s) into the tool trolley attached to the AGV and inputs a destination (OP number).**
- **The AGV follows the relevant route path to travel to a drop off station that corresponds to the OP requiring the tool change, drops trolley and returns to the tool crib.**
- **The operator walks to the drop of station 5-10 meters away from the machines to retrieve the tool.**
- **Operator conducts tool change.**
- **Operator inserts expired tool(s) back onto the same trolley and calls for collection**
- **AGV retrieves trolley containing the old tool(s) from the exact spot it dropped off and returns it to the tool crib.**
- **Tool setters collect the old tool(s) from the trolley so the holster(s) can be reused.**

7.0 IMPLEMENT

Due to the proposed closure of BEP, the findings of this report will not be implemented within the factory. However, due to Fords approach to maintaining familiarity between the plants selected to produce the Dragon engine, implementation within other Ford plants producing the engine is a strong possibility.

7.1 BILL OF PROCESS

Ford has adopted a Bill of Process approach all products related to Dragon to impose the standardisation of practices into the newest products. The AGV delivery system that has been subject to extensive research and planning throughout the entirety of this report has followed FMC guidelines and protocol from start to finish. Therefore, in retrospect, there should not be any problems with implementing this project in a different plant that produces Dragon, as everything about that line, regardless of where it is, should be identical to that of BEP.

7.2 MANAGEMENT OF CHANGE

The AGV delivery system that was designed in this report will not be implemented in BEP; however, the management of change and culture control aspects should still be recognised, as the project may be implemented in the China or Mexico plants in future.

As discussed in the literature review, the management of a change is essential for any project that drastically modifies an existing process for any hope of a successful outcome. This being as employees will become accustomed to a process and the particular way things are done. This means that they will likely be unwilling to divert away from what they perceive as normality to make way for the change, potentially causing conflict towards management and creating resistance. This especially applies to the design discussed in this report consisting of an autonomous vehicle, as it will require a substantial adaptation from the workforce.

The demeanour of this change is likely going to create resistance from the workforce as it is possible that they will feel threatened at the thought of being replaced by the autonomous vehicle. This could cause unrest within the ranks of the workplace and result in the change being vehemently opposed by the workforce. The resistance that is subject to the change can be significantly reduced if the change is managed correctly by the managers and supervisors who are enforcing it. If management explains the benefits of the change and how it will act as an advantage to the workforce, highlight the problems present with the current tool change process and explain the reasoning behind the change, then it will be better received by the workforce once introduced. The annual cost saving of £35,000 in

wages alone due to the wastes, followed by a potential £500,000+ in downtime costs if this project was implemented on Dragon machining should also be expressed to the workforce by management introducing the new process. Following these steps towards implementing such a change will have a far better outcome than an inadequate approach of taking control and forcing the workforce to accept the change for what it is and get on with it.

8.0 CONCLUSION & RECOMMENDATIONS

8.1 POTENTIAL COST SAVING

Although a cost-saving was estimated, the actual saving that this project could achieve if eventually implemented is much larger as the scenario used to estimate the duration of the downtime was an assumption based on the previous year of production. If the problem was left to escalate another year, then the downtime should, in essence, be far greater. The solidifying factor in the success of this project was the discovery that the one-off payment cost of the entire AGV project cheaper than the recurring annual losses in wage costs due to waste.

With the cost savings identified during the development of the final process, the project will cost £34,950. Compared to the waste cost of £35,566.40 and the potential cost of lost business due to downtime of £410,000, both of which will be recurring costs. The breakdown of the initial and recurring cost savings are as follows:

Downtime (5 hours) = £410,000 per year

Cost of Waste = £35,566.40 per year

Total = £445,566.40 per year

AGV Project Cost = £34,950 one off payment

AGV Waste Costs = £1750 per year

First Year Cost Saving = £445,566.40 - £34,950 - £1750

= £418,866.40

Recurring Cost Saving = £455,566.40 – £1750

= £453,816.40 per year

8.2 PROJECT CONCLUSION

The primary objective of this paper was to eliminate the wastes present with the current tool process as they were starting to cause problems with production and productivity.

The literature review was carried out to explore the basics of lean manufacturing and the measures and six sigma methodologies that can be implemented to enhance the lean aspects of a system and reduce waste. This research resulted in the six sigma DMEDI process being selected as the structuring technique to be used for the report. While researching material regarding wastes in manufacturing, the idea of an automated guided vehicle was discussed as a possible solution to the problem being faced by the project team. This particular interest led to further research being conducted into autonomous vehicles and how they operate, essentially paving the foundations for the remainder of the report.

The findings from the measure stage of the report were also vital, as the wastes present with the current tool change process were identified and calculated. The results that followed provided enough evidence for the project team to conclude that an AGV would be the ideal solution for the problem discussed in the define stage. This section also provided an estimate of the costs of the waste concerning wages, which would later prove vital to warrant the cost of the AGV system.

Before the development of the AGV system could commence, the current AGV technologies were explored by the project team to provide an idea of the capabilities of the AGV, as well as the costs to implement them. These costs were then directly compared to the cost of utilising additional labour to identify the cheaper solution, with the AGV system being the more favourable.

The utilisation of DFMEA and Poka-Yoke techniques were detrimental to ensuring that the project is accepted and implemented elsewhere. The thorough analysis of the conceptual design, using a Design FMEA to identify the potential modes of failure that were identified during a congregation between the project team and other employees within BEP. This allowed the project champion to fail-safe each point of concern, safeguarding that all bases are covered to certify a swift set up with minimal disruption.

The aim of this project was as follows:

Design a new tool delivery system for a machining line that reduces the wastes present with the current process to ensure that targets are consistently met.

When considering the following reductions, it is clear that this goal has been achieved.

Tool Changes = 9542 per year

Current Tool Change Process Waste = 97004 minutes per year

AGV Delivery System Projected Waste = 4771 minutes per year

Saving = 93233 minutes per year

On reflection, the problem encountered at the start of this report was in relation to employee productivity and how time was not being utilised accordingly. With an annual time saving of 93233 minutes, operators should not be able to utilise their time accordingly to ensure that they are fulfilling expectations of management and maintaining their area of work to prevent machines from degrading at an alarming rate.

The following objectives were set to ensure that the aim of the project is achieved. These were:

- Research lean six sigma project tools to broaden knowledge for undertaking a project like this to ensure greater efficiency and overall success.
- Collect and measure the data surrounding the current tool change process to prove that there is sufficient waste present to warrant the feasibility of a new delivery system.
- Research and explore current autonomous vehicles technologies that fit operational requirements as well as Ford Motor Company specifications.
- Compare the cost of this new system against the introduction of an extra man to warrant the project.
- Research and develop an autonomous tool delivery system that will absorb much of the wastes associated with the current tool pick-up and return process.
- Implement the new delivery system into BEP and report any findings or issues present.

The objectives highlighted green were successfully met by the project team, with the evidence included throughout this report. The only objective that was not met was involving the implementation of the project.

Unfortunately, due to the announcement by Ford of the proposed closure of BEP, it will never be known if this project would have the positive effect on production, cost savings and productivity that was predicted throughout this report, within the Bridgend site. Due to the winding down process of the plant, the effects that the problem had on production were less detrimental due to the barrage of other problems faced by management in the events after the fatal announcement. However, the findings of this report are intended to be implemented in other plants to avoid the same problem from occurring, meaning that the success or failure will be determined then. The future success will depend heavily on the management of change and culture approach taken by the FMC engineers tasked with implementing this project.

8.3 RECOMMENDED FURTHER WORK

Although this report has produced an AGV tool delivery system as a result of thorough planning and development, there is a large amount of potential for expanding the new system further.

When the process discussed in this report is eventually implemented, there will likely be a few minor problems, as with any new process. To reduce the severity of these potential issues, research should be conducted into the field of implementing similar AGV systems in different factories. Delegating time to study any relevant literature further or get in contact with engineers who have experience with such a system could be beneficial for gaining a better understanding of the dos and don'ts of working with autonomous vehicles.

To aid with the implementation of this project, this report could be converted to a summarised 6 Panel format, as this format is used by Ford engineers worldwide, to be issued to engineers in the Chinese and Mexican plants that will be producing Dragon post-2020. The management of change culture should be emphasised in this summarised version along with the cost and time waste savings to promote the success of the findings of the project.

If implemented successfully, the AGV tool delivery system could be expanded and utilised for other tasks on the Dragon machining lines. Further expansion would not be difficult, as the infrastructure of an AGV system would already be in place, meaning that engineers working on future developments could succeed by making small modifications to the existing system, rather than starting anew. Further work could also be conducted into improving the efficiencies of the new AGV delivery system. This could be achieved by focussing on minimising the congestion of the system or by working towards reducing the number of journeys made by each AGV.

The implementation of the new AGV tool delivery system will need to focus on enforcing the 5S strategies discussed in the literature review to reduce clutter and confusion when tools are being stored before being loaded into the AGV. Maintaining the work area is essential for this type of project as any clutter and untidiness will create delays during the loading and unloading of tools, eventually leading to an accumulation of waiting waste.

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10.0 APPENDIX

10.1 APPENDIX 1 – TOOL DATA

10.1.1 Headline Data

Magazine/ Station #	Tool Number	TCF [Parts]	TCF [Yearly]
OP 50			
1002	2358	1042	56.4
1003	2370	1075	54.6
1004	1502	3349	17.5
1005	3160	4524	13.0
1006	2179	5061	11.6
1007	4272	7655	7.7
1008	4273	6438	9.1
1009	2170	1626	36.1
1010	1519	3709	15.8
1011	2178	5487	10.7
1012	2171	5797	10.1
1013	4171	4697	12.5
1014	4172	8739	6.7
1015	4217	4859	12.1
1016	4218	4859	12.1
1017	4107	4195	14.0
1018	4104	4763	12.3
1019	2172	3102	18.9
1020	2173	8889	6.6
1021	2174	10500	5.6
1022	1526	10500	5.6
1023	2175	3209	18.3
1024	2176	3165	18.6
1025	2241	1216	48.3

Tool changes per year	386.2
No. of Machines	3
Total	709.6

Magazine/ Station #	Tool Number	Tool Life [Parts]	TCF [Yearly]
OP 100			
1003	1504	6317	9.3
1004	2177	1111	52.9
1005	5286	6391	9.2
1006	5285	17172	3.4
1007	5226	5891	10.0
1008	2160	2222	26.4
1009	2560	100000	0.6
1010	2161	12143	4.8
1011	5293	2569	22.9
1012	2360	1289	45.6
1013	2361	536	109.6
1014	5228	4849	12.1

Tool changes per year	306.9
No. of Machines	2
Total	613.7

Magazine/ Station #	Tool Number	Tool Life [Parts]	TCF [Yearly]
OP 120			
1002	8103	100000	0.6
1003	5289	10135	5.8
1004	5229	10559	5.6
1005	7102	2731	21.5
1007	6128	333	176.3
1008	6161	333	176.3
1009	6124	333	176.3
1010	6142	399	147.1
1011	6145	399	147.1
1012	5260	751	78.3
1013	5261	751	78.3
1014	1119	4990	11.8
1015	2660	2522	23.3
1016	4222	6721	8.7
1017	2696	3131	18.8
1018	4219	12920	4.5
1019	1204	13113	4.5
1020	1205	13540	4.3
1021	2362	11299	5.2
1022	5232	23364	2.5
1023	2363	1462	40.2
1024	7360	6007	9.8
1025	2364	11855	5.0
1026	2365	12085	4.9
1027	2162	9346	6.3
1028	1203	11534	5.1
1029	1503	16327	3.6
1032	2163	1407	41.8
1033	5295	1438	40.9
1034	1107	16163	3.6
1037	9102	1585	37.1
1040	9202	100000	0.6

Tool changes per year	1295.5
No. of Machines	3
Total	3886.6

Magazine/ Station #	Tool Number	Tool Life [Parts]	TCF [Yearly]
OP 170			
1002	8103	100000	0.6
1003	2164	3092	19.0
1004	5282	12157	4.8
1005	2165	5641	10.4
1006	2166	2859	20.6
1007	2661	9333	6.3
1008	2167	4133	14.2
1009	5294	10954	5.4
1010	5292	43478	1.4
1011	2366	1135	51.8
1012	5291	12581	4.7
1013	2367	10806	5.4
1014	2168	13256	4.4
1015	5227	60423	1.0
1016	2368	14959	3.9
1017	3104	53476	1.1
1018	2369	10727	5.5
1019	5236	12241	4.8
1020	2169	4938	11.9
1021	5234	14006	4.2
1022	5235	48462	1.2
1024	1106	449	131.0
1025	1109	449	131.0
1026	1115	1032	56.9
1027	4220	8526	6.9
1028	6125	10661	5.5
1029	6130	9107	6.5
1030	7322	1386	42.4
1031	7326	13223	4.4
1033	9160	1549	37.9
1034	9178	3789	15.5
1035	9202	125000	0.5

Tool changes per year	621.0
No. of Machines	2
Total	1242.1

10.1.2 Blockline Data

Magazine/Station #	Tool Number	TCF [Parts]	TCF [Yearly]
OP 50			
1005	1505	4412	13.3
1006	1508	4412	13.3
1007	9150	4412	13.3
1009	1707	22727	2.6
1010	1709	19608	3.0
1011	2653	1656	35.5
1012	7307	2200	26.7
1014	1550	5147	11.4
1015	2152	16779	3.5
1016	2150	18265	3.2
1018	1551	2694	21.8
1019	2654	7292	8.1
1020	4150	70028	0.8
1021	2655	6667	8.8
2001	1509	32609	1.8
2002	2123	10526	5.6
2003	4112	100000	0.6
2004	7318	12121	4.8
2005	2151	12956	4.5
2006	2650	14668	4.0
2007	2737	23333	2.5
2008	2738	41935	1.4
2011	2739	8389	7.0
2013	1564	22222	2.6
2014	2335	5714	10.3

Tool changes per year	210.6
No. of Machines	3
Total	631.8

Magazine/Station #	Tool Number	TCF [Parts]	TCF [Yearly]
OP 60			
1003	1510	2556	34.5
1004	1524	6150	14.3
1005	2311	1354	65.1
1006	1529	3365	26.2
1007	2329	729	120.9
1008	2313	8596	10.3
1009	7338	2149	41.0
1010	7314	1818	48.5
1011	2314	10667	8.3
1012	7325	11348	7.8
1013	2124	8844	10.0
1014	2651	22292	4.0
1015	7120	33333	2.6
1016	1507	11111	7.9
1017	2101	1806	48.8
1018	4117	28506	3.1
1019	1522	5128.21	17.2
1020	2154	10000	8.8
1021	2115	15231	5.8
1022	2750	7755	11.4

Tool changes per year	496.3
No. of Machines	2
Total	992.6

Magazine/ Station #	Tool Number	TCF [Parts]	TCF [Yearly]
OP 100			
1003	1521	19531	4.5
1004	4135	49140	1.8
1005	4137	45683	1.9
1006	4120	36284	2.4
1007	2321	7117	12.4
1008	2331	7117	12.4
1009	2322	3113	28.3
1010	2334	768	114.7
1011	2317	6890	12.8
1012	2314	6123	14.4
1013	7325	3245	27.2
1014	2652	7671	11.5
1016	7331	1277	69.0
1017	7314	4379	20.1
1018	2155	37003	2.4
1019	2100	12731	6.9
1020	4100	37369	2.4
1021	1563	7207	12.2
1021	1563	7207	12.2
1022	4146	18142	4.9
1023	4147	45662	1.9

Tool changes per year	376.4
No. of Machines	2
Total	752.7

Magazine/ Station #	Tool Number	TCF [Parts]	TCF [Yearly]
OP 170			
1011	2316	4814	12.2
1012	2156	9542	6.2
1014	1232	3731	15.7
1015	1252	3500	16.8
1016	1254	2453	24.0
1017	1456	2179	27.0
1018	9150	879	66.8
2001	2350	13431	4.4
2002	2656	8501	6.9
2003	2657	11209	5.2
2004	4130	9550	6.2
2005	4136	9601	6.1
2006	4133	19066	3.1
2007	4134	18139	3.2
2008	4141	3550	16.6
2009	4140	3550	16.6

Tool changes per year	236.9
No. of Machines	3
Total	710.7