CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	A methodology and trial implementation for digitising information on a factory floor
Authors	Duffy, Annie
Publication date	2019-10-04
Original Citation	Duffy, A. 2019. A methodology and trial implementation for digitising information on a factory floor. MRes Thesis, University College Cork.
Type of publication	Masters thesis (Research)
Rights	© 2019, Annie Duffy. - https://creativecommons.org/licenses/by-nc-nd/4.0/
Download date	2026-11-17 00:36:57
Item downloaded from	https://hdl.handle.net/10468/10081



UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh



UCC

University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

A Methodology and Trial Implementation for Digitising Information on a Factory Floor

Thesis presented by

Annie Duffy

For the degree of

Master of Engineering Science

University College Cork

Department of Civil and Environmental Engineering

Head of Department: Professor Liam Marnane

Supervisors: Dr Dominic O'Sullivan

October 2019

Declaration of Originality

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

Signed: Annie Duffy Date: 16/04/2020

Annie Duffy, 118227451

Acknowledgements

I would like to take the time to thank the following people who have supported me over the past year as I completed this research.

First, I would like to thank my supervisor Dr Dominic O'Sullivan for continuous advice and direction over the past year. Dr Peter O'Donovan has also been very helpful during this research. I would also like to thank Dr Ken Bruton for his feedback and guidance throughout the development of this project.

Special thanks for to Eymard Gorman and Richard Harrington for their role as industry support. Furthermore, thank you to Gemma O'Mahony, Jonathan Mulcahy and Dave Heelan for their assistance in completing the trials on the DMIN tool.

I am grateful to have had the support of my friends during this time. My colleagues Heloisa Lemmerts, Di Wang, Lara Hawchar, Angie Nagle and Kieran O'Leary in the UCC Civil Engineering post-graduate office, whose lunchtime conversations kept me motivated. Distinct credit goes to Alexander Brem, who helped christen the tool as the Digitised Manufacturing Information Nexus. Thank you to Edel McNerney and David Barry for their patience and reassurance over the past year as I adjusted to life in Cork.

Finally, I would like to show my appreciation to my family. My grandparents, mother, father and sister have shown me nothing but support, continually encouraging me to challenge myself and improve my abilities. My mother, Margo Duffy, and sister, Sarah Duffy, deserve recognition for their un-wavering endorsement of my capabilities, and for being inspirational women empowering me to achieve success.

Abstract

In recent years manufacturing industries have moved towards Smart Manufacturing, to achieve improved efficiency and production targets. Part of this innovation of current processes includes digitisation and improving access to machine information, usually through the introduction of new technology to assist with this transition. In order to maintain smooth processes and uninterrupted production, various information sources must be available on the factory floor. This project aims to provide a proof of concept for digitisation and access to necessary information during Pulse Walks. The methodology used to develop this tool is discussed. Observations during Pulse Walks were used to highlight the areas that this could be applied to, and a survey was used to determine the most useful information sources to include. Another aspect of this project is to introduce a method of digitally storing issues discussed during the Pulse Walk, to highlight recurring issues and problematic areas. This was developed to be used as part of the tool during Pulse Walks. This research will present a proof of concept for an app that will act as a digital information hub for accessing information and logging issues from the Pulse Walks. The use cases for this tool have been deliberated and the benefits clearly identified. This tool can assist with tracking recurring issues, using previously logged issues to create a historical database. The issue logging dashboard can be used for investigating reasons for machine downtime. This tool aims to improve production efficiency for a manufacturing line in a factory through issue tracking.

Table of Contents

Declaration of Originality i
Acknowledgements ii
Abstract iii
Table of Contents iv
Table of Figures vii
Table of Tables ix
Nomenclature x
1. Introduction 1
2. Lean Manufacturing 7
2.1. Background of Lean methodologies 7
2.2. Waste 9
2.2.1. Ohno's Seven Wastes 9
2.2.2. New Wastes 11
2.3. Kaizen 14
2.4. Jidoka 15
2.5. Visual Control 16
2.6. The Five Whys 17
2.7. Scheduling 17
2.8. Kanban 18
2.9. Gemba Walk 19
2.9.1. Pulse Walk 21
2.10. Summary 21
3. Digitisation 23
3.1. Digital Innovation 23
3.2. Smart Manufacturing 24
3.3. Industry 4.0 25
3.3.1. Internet of Things 26
3.4. Policy for Industry 4.0 27
3.5. Pillars of Industry 4.0 29
3.5.1. Big Data and Analysis 29
3.5.2. Autonomous Robots 30
3.5.3. System Integration 31
3.5.4. Industrial Internet of Things 31

3.5.5. Simulation 31
3.5.6. Cyber Security 32
3.5.7. The Cloud 32
3.5.8. Additive Manufacturing 33
3.5.9. Augmented Reality 33
3.5.10. Summary of Industry 4.0 33
3.6. Digitisation in Other Industries 34
3.6.1. Digitisation in Manufacturing 34
3.6.2. Digitisation in Construction 35
3.6.3. Digitisation in Aeronautics 37
3.6.4. Summary 38
4. Project Outline 39
4.1. Problem statement 39
4.2. Project Aims 42
4.3. Description of Tool 43
4.4. Methodology 44
4.5. Survey and feedback 48
4.5.1. Question 1 48
4.5.2. Question 2 49
4.5.3. Question 3 50
4.6. Data Sources 52
4.6.1. OSI Pi 52
4.6.2. Scrap Dashboard 53
4.7. Summary 53
5. Issue Logging and Data Analytics 54
5.1. Issue logging 54
5.2. Data Analytics 58
5.3. Development of Design 63
5.3.1. Demo feedback 63
6. Trial and Workshop 65
6.1. Trial Implementation 65
6.2. Workshop 67
6.3. Output from Workshop 68
6.3.1. Hardware 68
6.3.2. Data Sources 70

6.3.3. Issue Logging 72
6.3.4. Data Analytics 74
6.4. Discussion 78
7. Use Cases 80
7.1. Improving Information Access and Speeding up the Pulse Walk 80
7.2. Highlighting Problematic Areas 80
7.3. Energy Efficiency 82
7.4. Investigating Overall Equipment Efficiency 84
7.4.1. Example at GRND0048 85
7.4.2. Example at GRND0059 89
7.4.3. Example at GRND0054 92
8. Future work 95
8.1. Development of Design 95
8.2. Breakdown of project 95
8.2.1. Native Application 96
8.2.2. Web Application 96
8.3. Issue Logging 97
8.3.1. Adding Updates 97
8.3.2. Colour Coding 97
8.3.3. Checkboxes 98
8.4. Web Application Setup 99
8.4.1. Data Sources 100
8.5. Pulse Walk Screens 102
8.5.1. KPI board 106
8.6. Attendance 106
8.7. Qlik Dashboard 107
8.8. Technology 108
8.9. Implementation 110
8.10. Advancing ‘State of the Art’ in the Field 110
9. Discussion 112
9.1. Review of DMIN Tool 112
9.2. Communication 114
9.3. Conclusion 115
REFERENCES 118

Table of Figures

Figure 2.3-1 Shewhart and Deming cycle diagram [16] 14
Figure 2.8-1 Example of a Kanban board [18] 19
Figure 3.3-1 The history of Industrial Revolutions [38] 25
Figure 4.1-1 Map of Pulse Walk for FEMs Value Stream 40
Figure 4.1-2 Checklist on Grinders Pulse Walk board 40
Figure 4.1-3 Example of Pulse Walk white board table 41
Figure 4.3-1 Tool structure 43
Figure 4.3-2 QR code position in Value Stream 44
Figure 4.4-1 Methodology used for project 44
Figure 4.4-2 Online database of Pulse Walk entries 46
Figure 4.4-3 Finalised menu page for tool used during trial 47
Figure 4.5-1 Survey responses from Question 1 49
Figure 4.5-2 Survey responses from Question 2 50
Figure 4.5-3 Survey responses from Question 3 51
Figure 4.6-1 Pi Vision showing OEE 53
Figure 5.1-1 Checklist on digitised Pulse Walk board 55
Figure 5.1-2 Example of digitised issue log entry 56
Figure 5.1-3 Calculations for issues 57
Figure 5.1-4 Snippet of full digitised issue logging board 58
Figure 5.2-1 Issue count widgets 59
Figure 5.2-2 Graphs showing Number of Issues per Work step 59
Figure 5.2-3 Percentage split of lead time by Work step 60
Figure 5.2-4 Number of issues and details table 60
Figure 5.2-5 Lead time by Work step and Owners graphs 61
Figure 5.2-6 Issue Count per owner with lead times 61
Figure 5.2-7 Layout of Issue Insight dashboard 62
Figure 5.2-8 Issue Insight dashboard filtered to show GRND0048 data 63
Figure 5.3-1 Idea logging page 64
Figure 5.3-2 Qlik dashboard for OEE 64
Figure 6.1-1 Location of screen used for first trials highlighted in green 66
Figure 6.1-2 Location of portable screen for trial at Grinder step highlighted in green 66
Figure 6.3-1 Original path of Pulse Walk 69

Figure 6.3-2 Proposed path for future Pulse Walk 70
Figure 6.3-3 Example of the issue logging table including workshop feedback 73
Figure 6.3-4 Example of the KPI board with suggested changes 74
Figure 6.3-5 First three charts on the updated Issue Insight dashboard 75
Figure 6.3-6 Number of issues chart 75
Figure 6.3-7 Chart showing Total Lead time by Owners 76
Figure 6.3-8 Count of Issue by Owner with Lead time 77
Figure 6.3-9 Second three charts on the updated Issue Insight dashboard 77
Figure 6.3-10 Details table on the updated issue insight dashboard 78
Figure 7.2-1 Issue insight dashboard 81
Figure 7.2-2 Filtered issues by 'parts issue' 81
Figure 7.2-3 Issues filtered by GRND0078 82
Figure 7.4-1 OEE for GRND0048 for Tuesday 19th of March 2019 85
Figure 7.4-2 Unacknowledged downtime for GRND0048 18th-19th March 2019 86
Figure 7.4-3 OEE for GRND0048 Wednesday 20th March 2019 86
Figure 7.4-4 Unacknowledged downtime for GRD0048 19th-21st March 2019 87
Figure 7.4-5 Issues logged for GRND0048 87
Figure 7.4-6 OEE for GRND0048 on Friday 10th May 2019 88
Figure 7.4-7 OEE for GRND0048 11th - 12th of May 2019 89
Figure 7.4-8 OEE for GRND0059 Friday Day shift 15th March 2019 90
Figure 7.4-9 OEE for GRND0059 Friday night shift 15th March 2019 90
Figure 7.4-10 Unacknowledged events for GRND0059 15th-16th March 2019 91
Figure 7.4-11 Issues logged for GRND0059 91
Figure 7.4-12 Issues logged for GRND0059 during the week of 11th of March 2019 91
Figure 7.4-13 OEE for GRND0054 3rd - 4th of April 2019 92
Figure 7.4-14 Unacknowledged events for GRND0054 93
Figure 7.4-15 Issues logged for GRND0054 93
Figure 8.3-1 Code snippet for finding checkbox value 98
Figure 8.4-1 Example of Iframe code to embed a webpage into another webpage 99
Figure 8.5-1 First page of DMIN tool web app 103
Figure 8.5-2 Second page of DMIN tool web app 104
Figure 8.5-3 Third page of DMIN tool web app 105
Figure 8.7-1 Breakdown of data retrieval for Qlik dashboard 108

Table of Tables

Table 4.6-1 Description of data sources with survey response % 52
Table 5.1-1 Existing note-taking apps 54
Table 5.1-2 Example issue codes with corresponding actions 56
Table 6.4-1 Summary of survey suggestions..... 79
Table 8.8-1 Price comparison of interactive displays 108
Table 8.8-2 Price comparison of wireless mouse and keyboard 109

Nomenclature

5S	Sort, Set in Order, Shine, Standardize and Sustain
AEC	Architects, Engineers and Constructors
API	Application Programming Interface
AR	Augmented Reality
BIM	Building Information Modelling
COTS	Commercial-off-the-shelf
CPS	Cyber-Physical System
DBTH	Day-by-the-Hour
DMIN	Digitised Manufacturing Information Nexus
DT	Digital Twin
EFFRA	European Factories of the Future Research Association
ERP	Enterprise Resource Planning
FEMs	Femoral Implant Family
FoF	Factories of the Future
GDPR	General Data Protection Regulation
GM	General Motors
H2M	Human-to-Machine
HDMI	High Definition Multimedia interface
HTML	Hypertext Mark-up Language
ICT	Information and Communication Technology
Iframe	Inline Frame
IIoT	Industrial Internet of Things
IoT	Internet of Things
JIT	Just-in-Time
KPI	Key Performance Indicators
LCS	Low Contact Stress
M2M	Machine-to-Machine
MBWA	Management by Walking Around

MES	Manufacturing Execution System
MR	Mixed Reality
MRR	Material Review Report
NNVA	Necessary Non-value-adding
NUMMI	New United Motor Manufacturing Inc.
NVA	Non-value-adding
OEE	Overall Equipment Efficiency
OMS	Order Management System
PDF	Portable Document Format
PLM	Product Life Cycle Management
QMS	Quality Management System
QR	Quick response
REST	Representation State Transfer
RFID	Radio Frequency Identification
SME	Subject Matter Expert
TPS	Toyota Production System
UI	User Interface
URL	Uniform Resource Locator
VA	Value added
VR	Virtual Reality
VSM	Value Stream Manager
WIP	Work-in-Progress

1. Introduction

During the last decade, technological and digital advances have enabled improved manufacturing efficiency by incorporating interactive smart devices into production. Many of these devices are connected via the internet and can communicate with each other, making up the Internet of Things (IoT). This new phase of manufacturing is sometimes termed 'Industry 4.0', or the fourth industrial revolution. Following in the footsteps of previous innovations in industry, including electronic microchips at the end of the 20th Century; electricity in the 19th Century; steam power before that, Industry 4.0 also paves a new manner of production. Combining smart devices and machinery to improve manufacturing processes further improves control and management in manufacturing, enables greater efficiency, reducing waste of both time and material resources. Ultimately, this minimises production costs.

As the concepts of Industry 4.0 and the Internet of Things (IoT) have demonstrated widespread improvements in the areas outlined, today's industries use it as a driver in process innovation [1]. Factories are moving to align digital technology and production processes across the production line, optimising them by creating a fully digital end to end supply chain process. [2]. Consequently, digitisation is becoming increasingly prevalent in today's industries, facilitating a full digital life cycle of a given product. Implementing digitisation across a factory floor demonstrates improvements in the seamlessness of processes. Using digitisation to assist with product life cycle management (PLM) is regarded as a 'strategic weapon' in gaining competitive advantage by enabling a business to improve quality and reduce product-related costs [3] [4].

Numerous global policies have been introduced in recent years to drive innovative manufacturing through Industry 4.0. The Factories of the Future Public-Private Partnership is one such example. Launched by the European Commission in November 2008, this policy proactively encourages companies to invest in projects that promote their organisation's alignment with the goals for Factories of the Future (FoF) [5]. The policy advocates new technologies to innovate production and environment-friendly manufacturing. Implementing any or all of the targets set out by FoF is likely to be beneficial to both the production company and Europe on a broader scale. Similar drivers have been adapted in Germany, France and China each with the common theme of improving national manufacturing standards and process efficiency.

Improving efficiency in a factory is primarily about eliminating waste, including wasteful activities, and production of surplus or defective stock. This reflects the ethos of Lean manufacturing philosophies. While Lean focuses on waste removal, it also incorporates respect for factory workers' knowledge of a process. Lean, with the intention of streamlining, is initiated only after the manufacturing process has been minutely observed by those who are familiar with it. Process steps are mindfully considered to spotlight potential points where wasteful activities could be removed, thereby reducing waste and ultimately increasing productivity and efficiency. An example of Lean is the provision, usually through technology, of immediate access to machine and production information on the factory floor, which reduces time wasted searching for information or advice from other staff.

A mechanism to reduce waste occurring from the production of defective parts is another element where embedding digitisation and technology within a production process can aid efficiency. Enabling tracing of new and recurrent faults in tools or machines along the production line facilitates early identification of problems. It also improves understanding of how the fault occurs; supports improved maintenance, early replacement of faulty parts or machinery and ensures that appropriate steps are taken to minimise the reoccurrence of the same issues. This immediacy enables continuous improvement of the production line and increased energy efficiency of the factory since less energy and resources are wasted reproducing those faulty parts. Less time is lost dealing with recurring defects because the perpetrating issues will have been identified and dealt with [6].

As factories increasingly integrate innovative technologies and energy efficiency grows, the drive for more environmentally friendly and improved sustainability of the process also increases. Countries across the world have entered into a pact to preserve global temperatures to less than two degrees Celsius warmer than pre-industrial times, called the Paris Agreement [7]. Functioning at the highest possible efficiency is crucial in the climate crisis we are experiencing today, to support the Paris Agreement and minimise global warming. Increasing energy efficiency has been suggested as one of the most effective measures to mitigate greenhouse gas emissions, thus reducing the impact of climate change [8].

This research poses the question, "Does digitising improve efficiency in manufacturing?"

The project is supported by an industry partner, a manufacturing facility who develop a range of medical devices. Each device is separated into Value Streams containing process steps for

each type of product. This research is involved in one particular Value Stream, the Femoral Implant family, referred to as FEMs. The medical device facility produces product continuously, with machines operating 24 hours a day. Due to the nature of staff hierarchy, commonly weekend and night shift are staffed by largely junior and less experienced team members. Increased error and associated waste, thus production costs, tend to be prevalent during these times. By aligning technology and digitisation with the production line, it is possible to reduce this. The challenge is to provide support for Operators through timely access to information.

In seeking answers to the research proposal, this project aims to innovate the current Pulse Walk process in this medical device manufacturing facility by incorporating Lean manufacturing philosophies and digitisation into the production process. A Pulse Walk is the action of Team Leads physically walking the production line and spending time with Operators, with the intention of identifying and finding solutions to issues as they occur on the manufacturing line. It is common practice to capture problems and solutions on whiteboards, which are then erased once resolution has been achieved.

As part of the research project, this company's manufacturing process is observed and discussed with Operators and Team Leads along the Pulse Walk, and areas for potential improvement discerned. A computerised Pulse Walk tool referred to as a Digitised Manufacturing Information Nexus (DMIN) has been developed by the author to provide Operators with immediate access to manufacturing information and provide a digital version of the Pulse Walk whiteboards. This function enables retention of entries in a database, facilitating access to historical issues and aiding resolution through identification and investigation of recurring issues.

The DMIN tool is ultimately intended to improve efficiency in the manufacturing process in two ways. Collecting and storing data creates an alert to recurring issues, makes early identification possible, helps pinpoint potential causes, the best approach to correction and ultimately enables their eradication from production. Additionally providing immediate Operator access to production and equipment data minimises time wasted in searching for information. This drive for efficiency and removal of waste reflects Lean manufacturing philosophies and the aspirations of FoF.

A whole system approach has been facilitated through invaluable co-operation and support from the production team. This provides a unique opportunity for input from staff working on the factory floor throughout the research and development of the DMIN tool. The manufacturing facility continuously provided feedback at each stage of project development and this ongoing communication provided distinctive insight into the Pulse Walk process and areas for potential improvement. Crucially, open dialogue and engagement has enabled the end user to influence the project outcome which is vital if it is to be fit for purpose and accepted.

The facility also provided access to the factory floor, allowing for the DMIN tool to be trialled as part of the Pulse Walk. The ability to demonstrate and trial the DMIN tool within the existing manufacturing processes has provided users with evidence that it is of benefit and allowed consideration of ways to maximise its potential in improving efficiency and reducing waste in all areas of production.

While the manufacturing facility already employs some aspects of Lean methodologies, this research investigates other strands of Lean manufacturing philosophies to locate and remove waste from manufacturing, exploring additional options that could be introduced to the factory.

Digitisation is a crucial part of this research, including Smart Manufacturing, IoT and Industry 4.0. These features are examined, including the Pillars of Industry 4.0 used in factories around the world. Taking inspiration from these and the goals of Industry 4.0 and FoF has cultivated the development of the DMIN tool.

The project undertaken improves access to manufacturing and process information at Operator level and additionally initiates the digital logging of issues discussed on the Pulse Walk to build a database of real problems encountered and best solution options. These goals align with Lean manufacturing philosophies to eradicate waste from the production process and by introducing digitalisation and adapting the use of the developed Pulse Walk tool, the factory is moving rapidly towards Industry 4.0. The methodology used to develop the DMIN tool to implement digitisation and access to information from a factory floor is explained in this research.

The breakdown of this thesis is as follows; Chapter 2 discusses the background research into Lean methodologies. This chapter considers the many facets of Lean manufacturing and how it is currently implemented in the medical device factory.

An investigation has been completed into Digitisation in Chapter 3. This section looks into the birth of Smart Manufacturing, IoT and Industry 4.0. Industry 4.0 is examined, highlighting how other industries are introducing it through digitisation and the technologies used to support it.

Chapter 4 confers learning from this research to outline the specification and plan for the DMIN tool, what is included, and how it will be implemented. The methodology used during the development of this project is also broken down and explained in this chapter. This is followed by a detailed description of the survey used, and the responses gathered. From the survey results, data sources suggested to include in the tool are presented as part of the proof-of-concept DMIN tool.

The development of the digitisation aspect of the DMIN tool is explained in Chapter 5. The Pulse Walk boards have been digitised for inclusion in the DMIN tool and steps taken to build these are clarified. Additionally, data recorded in these digitised boards from the Pulse Walks has been used to create a dashboard in Qlik, a data analytics software used by the medical device manufacturing facility. This dashboard uses real data collected from Pulse Walks to provide insights into the issues encountered, identify where most issues occur and which are most prevalent.

Chapter 6 discusses the trial and workshop that took place after the DMIN tool was developed. The tool is trialled at various points of the Pulse Walk on both an iPad and portable screens to gain an understanding of where it could be most useful and benefit production. Within the trial issues are captured in the digitised version of the whiteboards, evidencing to staff how the DMIN tool would work and providing opportunity to learn how to use it. Following the trial period, a workshop ran with various staff members to examine the DMIN tool in detail and identify areas to improve user experience. This workshop was split into sections exploring the best hardware options and data sources to include, alongside suggestions collected during the survey and resulting from previous trials. Discussions also examine the digitised issue logging tables and the Qlik dashboard, to determine suitability and fit with the information collected by the DMIN tool.

Chapter 0 outlines four use cases for the DMIN tool. After trialling the DMIN tool on the factory floor, the benefits of using it become immediately clear. The primary advantage is ease of access to pertinent manufacturing information from multiple sources located in one place where and when it is needed, without having to open a laptop or go into an office. The second

highly valuable aspect of the DMIN tool is the digitised issue logging table. The digitised version of the Pulse Walk board stores historical entries, enabling identification and tracking of recurrent issues logged at machines. This digitised table can be used to highlight problematic areas or work steps that are experiencing a large volume of issues. Consequently, this feature enables the management team to identify points in the production process that require attention to reduce waste and replace damaged parts, in turn reducing faulty product. Ultimately, resource waste can be minimised, and the efficiency of the Value Stream improved, so the DMIN tool has the potential to improve the overall energy efficiency of the factory. This use case aligns the DMIN tool with the targets for FoF and Industry 4.0. The final use case for the DMIN tool became obvious when investigating Overall Equipment Efficiency (OEE) of machines in the Value Stream. Low levels of OEE have been recorded for machines, but with no reason logged to explain why. Using the digitised issue log of the DMIN tool, it is possible to track issues which may have impacted machine operation levels. This can assist management in understanding what influences OEE levels, including those due to planned maintenance or caused by issues logged as part of the Pulse Walk.

Following the trial and use cases, a plan of future work to develop the project is outlined in Chapter 8. This details the requirements to develop the proof of concept DMIN tool into a fully-fledged web application for use on the factory floor. The conclusions of this research are discussed in Chapter 9, including a review of the DMIN tool.

2. Lean Manufacturing

Lean manufacturing methodology aims to reduce waste, while maximising productivity and efficiency. It encompasses a range of tools familiar to the manufacturing industry, focusing on continuous improvement underpinned by a problem solving approach. Lean methodology sees mistakes as opportunities for improvement and aims to create best value for customers while keeping production costs to a minimum [6]. Jim Benson of Modus Cooperandi described it as "both a philosophy and a discipline which, at its core, increases access to information to ensure responsible decision making in the service of creating customer value" [9].

2.1. Background of Lean methodologies

Japan, in particular the car manufacturer Toyota, is the birthplace of Lean methodologies. Taiichi Ohno, who served as Vice-president of the Toyota Motor Company is sometimes considered the 'grandfather of Lean manufacturing' and founder of the Toyota Production System (TPS). He believed that the drive to improve should not stop, rather a drive to learn and implement better ways to increase product quality and productivity should be constant.

The ideology behind his belief is derived from Japanese culture and history. Traditionally Samurai warriors consistently sought to improve and perfect individual style and ability. Taiichi Ohno believed this philosophy of continuous learning should be adopted by managers and directors in Toyota. By constantly learning and perfecting their managerial style and skillset, processes and production could also improve. [10].

Japan lacks many natural resources, creating dependency on imported materials. In turn importing creates high raw materials cost, potentially placing the country at a financial disadvantage. However, to overcome this, Japanese industries seek to create goods of better quality and higher added value, while keeping production costs lower than other countries [11].

A predominate trait of Japanese culture is a positive attitude towards work and equality. 'Group consciousness' or collectivistic thought developed in the Japanese food farming industry where communities work together to support the labour intensive growth of their primary food source, rice. In contrast, western culture tends towards a more individualistic outlook, as historically the primary food source in the west – wheat – could be farmed independently, which has led

to western society being less community dependent [12]. Education standards in Japan are high and traditionally life centres around work. Generally company employees remain with the same company for life and opportunities for advancement are numerous, which in turn promotes a sense of unity between companies and workers [11].

While Toyota's focus was eliminating waste and minimising costs, it recognised the workforce's capabilities as a valuable resource in the drive for production improvement. To eliminate waste, they assumed that anything other than the minimum amount of equipment, materials and working time that is essential is surplus and will thus raise the cost. This led to a focus on cost-cutting measures through waste removal and the 'Just-in-Time production' and 'Jidoka' approach to this will be discussed later [11].

An insight into Lean methodologies and their benefit to an organisation is explained in "How to Change a Culture: Lessons From NUMMI," [13]. This paper gives a first-hand account of process innovation in New United Motor Manufacturing Inc. (NUMMI) a joint venture between Toyota Motor Corp. and General Motors Co. (GM).

The research question posed by J. Shook is "How can managers change the culture of their organisation", and the response is largely based on how problems are solved. Cultivating employee involvement is key to Toyota's production system, linking interactive teamwork to quality improvement and problem-solving approaches. After introducing Toyota's Lean inspired methodologies, the GM factory reported significantly lower levels of absenteeism and higher levels of production quality.

According to Shook, western mentality towards process improvement attempts to change attitudes and aims to get the whole workforce to think the 'right way'. In contrast, experiences from NUMMI suggest cultural change is achieved by changing peoples' behaviours. Jerry Sternin's quote summarises this, "It is easier to act your way to a new way of thinking than to think your way to a new way of acting" [13]. Defining the desired behaviour through education and any necessary reinforcements, work place culture undergoes change. Shook suggests that crucially Lean manufacturing creates a cultural shift around problem-solving and transforms manufacturing [13]. The 'Andon' system is a process that builds quality by exposing problems, this will be discussed in Chapter 2.4. Rather than apportion blame, Lean repeatedly asks "why" until the reason is found and this is discussed further in Chapter 2.6.

Fundamentally, Toyota created tools to make it easy to detect and resolve problems while learning from mistakes, which Shook describes as "the Lean cultural shift" [13]. By

approaching problems and mistakes as a learning and improvement opportunity, attitude towards encountering problems is fundamentally changed.

'The triumph of the Lean production system' is discussed by J. F. Krafcik, in his research investigating how manufacturing plants can improve their efficiency. He challenges a widely held belief in the auto industry that quality and productivity are influenced by plant location, a variety of factors impacting manufacturing performance are identified. These range from corporate parentage to management philosophies and Lean management policies that provided higher performance and improved productivity and efficiency [14].

In contrast to all that has been discussed, Krafcik notes that many efficient factories do not employ Lean methods while some 'Lean' factories that are not very efficient. To be effective, Lean policies require highly skilled management and discipline which takes time to achieve but can also provides a company with more flexibility in what they can manufacture, while maintaining high levels of quality and productivity.

2.2. Waste

While waste is endemic to manufacturing, removal of waste is a key feature of Lean methodology. Lean dictates that every member of staff should work towards preventing waste or 'Muda' in all aspects of the factory but to effectively eliminate a process of waste, it first has to be found [6]. Lean methods work to highlight wasteful areas so they can be targeted and dealt with, additionally striving to prevent the waste from occurring in the future.

2.2.1. Ohno's Seven Wastes

Multiple sources of waste exist in any manufacturing facility, and can be divided into categories known as 'Ohno's Seven Wastes' [10] [6]:

1. Waste from overproduction

Considered the most severe waste in Lean manufacturing, overproduction is the basis of many other wastes [6]. Waste in this category is a result of processes moving too fast on the factory floor as workers cease to wait between their designated jobs and instead continue to produce

more than what is necessary, causing a build-up of materials or parts at each step of the production line [10]. The aim is only to produce what is necessary at each stage to maintain smooth production flow.

2. Waste from waiting

Waiting occurs when workers attend automated machines without being able to do anything productive due to the machine being in use. To remedy this, scheduling can help order which machine to use facilitating best use of workers time. This type of waste also occurs if parts or materials have not been delivered on time, causing delays to production [6].

3. Waste from transportation

Waste from this category is a result of unnecessary movement of products that have been put into temporary storage. Occasionally parts have to move around a factory to go through different processes and streamlining this, alongside scheduling can reduce this waste. Other causes for delays in this category can be due to the movement of materials and parts from the warehouse to the factory, where the stock must be sorted and arranged [10].

4. Waste from processing

Processing waste occurs when a machine breaks down, causing delays in manufacturing. If reprocessing is required for parts, it too falls under this category [10]. Inappropriate processing that is running a machine consistently instead of only when needed, or machines or processes not capable of producing parts to a standard of quality expected by the factory and require further work are also included in this category [6]. To avoid such issues occurring, the solution is to work to defined processes and have training available for staff who will be using machines to ensure they are doing so correctly.

5. Waste from stock on hand

Stock on hand, or inventory, is to be avoided as much as possible in Lean manufacturing. Although it is impossible to keep zero inventory, it is imperative to aim for as close to it as

possible as adding stock leads to adding lead time and can mask problems with the process line or production schedule [6].

6. Waste from unnecessary motion

Unnecessary motion can refer to human and layout. Human-based unnecessary motion can be avoided by ergonomic designs of workstations to avoid stretching, bending, or any exertion required to position themselves better to do their work [10]. If there is any hurt to the operator, this can have an impact on quality, eventually impacting the customer. The layout of a factory is vital to abolish any wasted motions or waste from transportation discussed above and machines should be laid out in a logical order to avoid unnecessary movement between them during the production process [6].

7. Waste from defective parts

Producing defective parts has associated monetary and time costs, escalating the longer they go undetected. Themes that are followed in Lean manufacturing deal with maintaining the quality at the source, and the chain of quality throughout the production process. In Toyota, defective parts are considered a challenge for improvement, although most manufacturing firms aim for ‘prevention, not detection’ in a bid to avoid creating defects in the first place [6].

2.2.2. New Wastes

In recent years new wastes have been outlined that build from Ohno’s original list, to cover service and manufacturing flaws [6].

1. Waste from making the wrong product efficiently

This waste involves the original principle of Lean manufacturing. It is closely related to the waste of overproduction. This waste deals with efficiently producing the wrong items or products.

2. Waste from untapped human potential

Taiichi Ohno aimed for Toyota to create ‘thinking people’, this is described in the Lean methodology as seeking ideas and inspiration from the factory workers about how to improve quality [6]. Clear communication and commitment are necessary to support this human potential. Methods of acquiring this feedback can be through Gemba walks, which will be discussed in detail later in this chapter. The key to avoiding this waste is to listen to the creative potential of employees and respect their input.

3. Waste from excessive information and communication

An abundance of information exists in today’s workplace, such as emails, textbooks, and articles. Although they all may contain useful information, it is essential to focus on the key points and not get bogged down in excessive information. This includes management, specifically meetings which should be necessary and concise to relay the desired information as efficiently as possible.

4. Waste of time

Wasted time affects everyone, and everyone is guilty of doing it. This waste describes the need for time management to focus on all tasks, not just the urgent ones, to keep all tasks from becoming overwhelming or getting out of hand. This can be managed by setting blocks of time aside for each task, not just prioritising the urgent ones [6].

5. Waste from inappropriate systems

This waste describes the use of unnecessary systems, not just in production but in the paperwork involved in the production. To keep production streamlined, these must be efficient and not cause delays in manufacturing [6].

6. Waste from energy and water

Energy here refers to power sources such as electricity, gas, and coal. Avoiding waste in this area is essential to sustainability in all industries. Energy management is very prevalent with

the climate crisis looming, and many industries have institutionalised energy efficiency. This can begin with small steps such as switching off unnecessary lights and powering down un-used machinery.

7. Waste from natural resources

Continuing from the previous point, avoiding waste of resources is imperative. Paper is an example; most offices use paper in various ways for meetings and sharing information with others on the factory floor and moving to a paperless work environment will avoid this waste [6].

8. Waste of 'No follow through'

By not completing waste reduction to improve processes creates waste. An example would be rearranging a factory floor to reduce walking distance mid-process to save time. If nothing productive is done with the newly spared time, it is considered a waste as it does not improve production [6].

9. Waste of knowledge

As production takes place, improvements and knowledge from experiences should be noted. Waste in this category occurs when this knowledge is not recorded and then forgotten about [6]. It is related to untapped human potential as sometimes as things are learned, they are kept with the person who knows them. This causes issues when that person is unavailable, and other staff members do not possess the same level of experience or knowledge in a particular area. To avoid this improvements and experiences should be noted down, and information shared amongst all staff involved to ensure a collective knowledge is achieved.

Other wastes involved in manufacturing include duplication of data when it has to be re-entered twice, unclear communication about product status and incorrect inventory [6]. These wastes are not usually considered impactful on the customer, but in a manufacturing facility, they can cause problems for production.

These wastes can be managed through scheduling using Kanban (which will be discussed in Chapter 2.8) and outlining a production plan that takes into account the possible areas were

waste can arise. Waste is considered a partner of innovation; it must be dealt with to welcome innovation and improvements to production. Removing waste is achieved by studying issues and introducing facility improvements to support process innovation through new devices or equipment [10]. Facility improvement is part of the Toyota production system and includes the introduction of new devices and technology to assist with providing minimal waste for a manufacturing process [15]. Introduction of new technology is discussed in Chapter 3.

Lean is considered to be a 'tool-box' that has a variety of aspects, that can be adapted or modified to as required. Some Lean methods are discussed below.

2.3. Kaizen

Kaizen is a Sino-Japanese word that means 'good change'. It is the act of continuous improvement through small changes [16]. It is applied to manufacturing in Toyota firms and other companies that employ Lean methodologies. Kaizen is based on the belief that nothing is perfect; thus everything can be improved. It is usually treated as a cycle, similar to the Shewhart or Deming cycles which are made up of four steps, "Plan, Do, Check, Act", described in Figure 2.3-1.

Kaizen can be applied to many aspects of manufacturing. The core values are in line with the traditional Lean ideologies, such as targeting zero waste, empowering people and being transparent with data all the while improving processes.

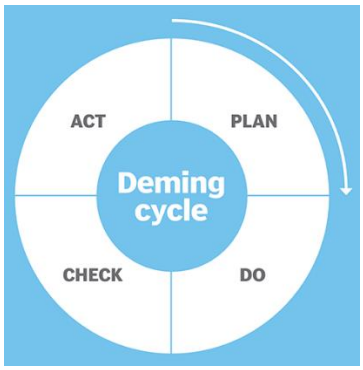


Figure 2.3-1 Shewhart and Deming cycle diagram [16]

Kaizen aims to improve productivity and manage any inefficiencies through proactive solutions. The rules of Kaizen are as follows [16]:

1. Let go of assumptions
2. Be proactive about solving problems
3. Do not accept the status quo
4. Let go of perfectionism and have an attitude that supports iterative, adaptive change
5. Look for solutions as mistakes are found
6. Create an environment in which everyone feels empowered to contribute
7. Do not accept the apparent issue; use the 'Five Whys' method to get to the root cause
8. Cull information and opinions from multiple people
9. Use creativity to find low-cost, small improvements
10. Never stop improving

The following strands of Lean manufacturing methodologies employ Kaizen in various ways.

2.4. Jidoka

Toyota aimed to have a manufacturing system that was 'automation with a human touch', that is automated machines that could be assisted by humans to provide a more intelligent process. This can be used when an automated machine must be stopped by human interaction in the event of a defective part, or scrap clogging the machine. Enabling this human interaction stops problems on the machine being exacerbated and causing further difficulties [10]. This was achieved through 'Jidoka' known as "Stop the line", where each worker has a stop button for the process line when an event occurs that will cause issues or damage. This is part of Toyota's commitment to enabling employees to build in quality and reach their full potential [11] [13]. Jidoka means "to make equipment or operation stop whenever an abnormal or defective condition arises" [11]. Each time the line is stopped, the process should be improved in some way so that the same issue does not reoccur.

Jidoka is fundamentally respectful of employees, and was initiated as a way of giving workers the capability, control, and obligation of physically stopping the production line when they

encountered a problem [10] [12]. This allows workers to be engaged in problem-solving and making improvements while integrating quality, support and ownership into each job in the factory. Toyota believes successful manufacturing comes from “men that operate a conveyor, not a conveyer that operates men” and is vital in respecting for their workers’ independence [11]. Furthering this point, Toyota provides each worker the opportunity to improve their process, or any waste, he or she has found.

Andon lights are boards that indicate which part of the line has been stopped [11]. They can also be used to highlight when a machine has broken down, or something has gone wrong on the factory floor. Using Andon shows managers and supervisors which area is causing problems [17]. This is called ‘Visual control’, enabling detection and improvement of problematic areas.

2.5. Visual Control

Visual control is used to gain a better understanding of a factory by creating an ‘easy-to-observe’ workplace [11]. This evidences any gaps in workload as it will be easy to spot workers with extra time on their hands and also draws attention to inefficiencies, such as the unnecessary movement of parts or machines that break down.

The following steps are a guide for introducing visual control to a factory [10]:

- Determine the locations

This is used to outline the locations of materials and parts, which are noted on the Kanban. This will assist in managing any irregularities with storage or movement of parts.

- Erect an Andon lamp

This lamp is discussed in Chapter 2.4. It is used to highlight any issues encountered on the line that requires the manufacturing process to stop.

- Display a Kanban for the line

A Kanban will detail the work in progress and status of parts. Displaying this on the line will share the information with managers and workers, providing information about cycle time, stock and procedures. Kanban is further discussed in Chapter 2.8.

Visual control is a significant aspect of successful Lean manufacturing. It involves improvement, rapid problem management, transparent scheduling, involvement and teamwork [6]. It supports JIT manufacturing, allowing machines to operate as usual in normal conditions and allowing staff to practise abnormality control where necessary.

2.6. The Five Whys

Lean manufacturing aims to streamline production activities. If there are any problems on the floor, they must be recognised. To ignore any predicaments will only exacerbate the situation creating more delays and thus, waste. To fully understand issues encountered on the factory floor, the TPS uses 'The Five Whys' or the Five W's.

This method has the managers asking 'Why, why, why, why, why?' followed by 'how'? The Five Whys strategy is used to discover the source of a problem rather than, 'who, what, where, when, why?' The latter form of questioning points blame to the operators on the floor which can lead to staff hiding issues concerned that they will be unfairly accosted. Using Lean, managers avoid blame instead aiming to fully understand the root of the problem to rectify it [10].

2.7. Scheduling

An important aspect of Lean manufacturing methodologies is the scheduling of processes. It is vital to correctly plan the time and order of which products should be manufactured. Lean methods want to avoid large surplus, so each process should only produce the exact amount required at that stage. If a process begins to move too fast, irrespectively of the process happening either side, stock can begin to pile up on the factory floor [6]. If the process is not

required to be in production at that time, it is not efficient to have the workers idle on the factory floor. To avoid the overproduction of parts mid-process, and also avoid idle workers, scheduling is necessary to create a production plan that allows the continuous flow of manufacturing for a smooth flow from the start to finished product.

Scheduling also allows managers to plan when machines should be in use. This can allow them to allocate times when the machine should be switched off to save power instead of having it sit idly if it is not in use.

2.8. Kanban

Kanban is used in Lean manufacturing as a means of supporting the scheduling of production. There are various styles of Kanban that can be used in a factory. Single card Kanban is where there is a card or pull signal between stations. This indicates when to make a part, and to move it to the next location.

Kanban means ‘card’, a visual record used to convey information [15] [18]. A Kanban system can be used as a production control system to monitor manufacturing [19]. A Kanban consists of a board used to visualise workflow, showing stages of the process such as ‘do, doing, done’ [20]. This allows people to see the status of any work being completed instantly. Examples of information shared by Kanban is as follows [10]:

- What to produce
- When to produce it
- Quantity to be produced
- Methods for production
- Standard procedures
- Amount to be moved
- Location to be moved to
- Storage location

Using Kanban allows for the rapid acquisition of precise facts regarding the current state of production. Kanban allows workers and managers to quickly gain an understanding of the progress of the manufacturing process [11]. It also enables workers to identify any problems

with production flow and synchronisation of inventory [21]. An example of a Kanban board is shown in Figure 2.8-1.

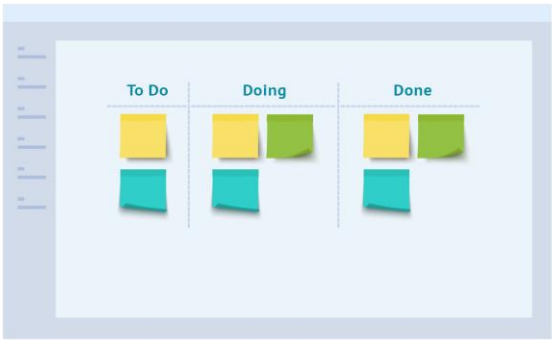


Figure 2.8-1 Example of a Kanban board [18]

A feature of Kanban is to limit Work-in-Progress (WIP). Limiting the number of things that can be done at once can improve the quality and efficiency of the work [20]. Keeping WIP levels low and minimal inventory improves the flexibility of the system [21].

Kanban can also refer to a container which has a card designating what should be produced, and in which location. This can be used for managing production on a factory floor [6]. This form of Kanban is designed to move with the parts within the factory, containing information regarding the parts it contains for distribution within the factory. This allows for the parts to be recognised, to avoid them being 'lost' in the factory [10].

Although Kanban can be used to share specific information about parts and materials used in production, to have a successful Kanban system, it is essential to not have an abundance of information. A precise Kanban system uses the minimum amount of Kanban required to share the information. If there are too many Kanban's in use, they can hide any problems from being corrected due to an overload of information that may not be wholly accurate [10]. For a Kanban system to work well, it must succinctly share useful information.

2.9. Gemba Walk

Another Lean methodology that is widely used in various manufacturing factories to improve operational efficiency is the Gemba walk [22]. The term 'Gemba' is Japanese and means "the

real place" and is also known as 'Management by walking around' (MBWA) [23]. It describes when managers and leaders take regular tours around the factory floor to observe processes and pinpoint wasteful activities and is a useful tool for managers to be connected with operators and other staff on the factory floor. Gemba walks are teaching exercises as they allow managers to experience the shop floor's operational reality, which might not align with the theoretical reality [24]. These walks highlight how processes differ from Standard Operating Procedures (SOPs) or conditioned assumptions. Witnessing the actual flow of processes should enable managers and other staff who are not familiar with the process to seek an understanding of why there might be differences in processes. The focus of the Gemba walk is to understand how value is being added or subtracted from the actual process; this is achieved by all walkers practising active listening [24].

Executing regular Gemba walks allows companies to make more informed decisions surrounding their processes, using real-world data. Gemba aims to go to the factory floor instead of the traditional office setting to collect facts rather than opinions regarding production [6]. Collecting and understanding this data is a vital to Gemba walks, assisting in aligning a manager's perception with the reality of processes [22] and gain understanding of where issues can arise actions and reasoning of the operators.

The key elements of a Gemba walk are as follows [22]:

- Observe, do not correct
- Seek to understand
- Value-added activities
- Locate areas that are subtracting value
- Innovate and improve conditions, tools, and procedures

Gemba promotes positive attitudes in the workplace by empowering employees to be able to discuss issues with managers. This alters any attitudes that people may have had before, where they may have shrugged off the responsibility of improving a process. Instead, allowing open and honest discussions on the factory floor aids improved mentality towards reducing waste and preventing issues in the future [6].

Gemba is often used in conjunction with Lean elements such as The Five Whys, Kaizen and 5S among others, which is usually specific to each company and factory. Implementing Gemba

walks can be a powerful innovation tool for companies if done correctly [24]. For a Gemba walk to succeed a factory must use the right equipment to make information sharing simple, such as a rolling whiteboard or screen. Encouraging accountability for staff presence on the walks can be achieved by taking attendance of staff or department representation. As an output of the meeting, the next steps should be clearly outlined for all involved parties and any new owners of issues. A support system should be in place to tackle any issues experienced as practising a blame-free culture is fundamental to a successful Gemba walk and a healthy work environment where all parties are involved in learning and understanding [24].

2.9.1. Pulse Walk

The factory used in this research uses a variation of a Gemba walk, namely a 'Pulse Walk'. This Pulse Walk involves various members of staff:

- Operators
- Line facilitators, who are operators in charge of over-seeing the machines in their area
- Team leads
- Engineers
- Quality
- Maintenance staff

The staff walk along each step of a Value Stream, which typically produces a specific type of part. At each step, any issues that have been encountered at any work step or machine are discussed. This allows operators a chance to provide feedback to managers and Team Leads regarding issues with machines, other equipment or delays in production. These discussions allow those involved to collaborate as a team to find and fix problems and highlight the weak points of a process. Discussion between each level of command, allows operators, maintenance staff and Team Leads to find solutions to problems at various stages of production [25].

2.10. Summary

The medical device manufacturing facility used in this research already employs Lean tools such as Kanban and The Five Whys method alongside the Pulse Walk. To further improve efficiency and avoid the many possible wastes described in Chapter 2.2, this project aims to

introduce more Lean concepts to this manufacturing process. Employing the well-established Pulse Walk it is possible to enable waste location and derive an effective solution to it, through the creation of a database to record and search through historical issues. Highlighting the issues encountered will draw attention to problems, and more importantly, previously used solutions. This will allow managers to take further action if there are repeated problems with a specific tool or machine.

The ambition of this research is to innovate the Pulse Walk to allow for improved communication and feedback to staff from managers. As discussed in this chapter, Lean focuses on respecting workers opinions and seeks to build on abilities by giving more responsibility in the factory. Equally enabling Operators to suggest ways to improve processes can be beneficial to production since managers are unlikely to be as familiar with processes. It is hoped that this approach has a positive impact on workers attitudes, as illustrated by Shook [13]. Lean concepts will be considered during the development of this project as an output goal for the developed tool to highlight and reduce waste while improving communication.

3. Digitisation

'Digitisation' in its purest form is the conversion of analogue information to digital information [2]. There is some ambiguity between the definition of digitisation and digitalisation [26]. 'Digitalisation' is defined as "the use of digital technologies to change a business model and provide new revenue and value-producing opportunities" by Gartner [27]. Digitising aspects of a process usually results in the digitalisation of the same process, as technology such as smart devices are introduced to support the digital innovation [24] [25]. For the sake of this research the term 'Digitisation' will be used, referring to both the conversion of data into a digital format and the introduction of technology to facilitate such transitions.

Digitisation involves:

- Standardising data
- Collecting data
- Converting data into a usable format

When the standardised data has been collected, it can be analysed to understand the insights the information is providing.

Digitisation and digitalisation have a part to play in Smart Manufacturing. Industry 4.0, the term being used to describe a new phase of manufacturing that incorporates smart devices through Smart Manufacturing and the Internet of Things (IoT). Smart Manufacturing is when all devices and machines connect via the internet to other devices and processes enabling automation and improved decision making.

As industries move towards Industry 4.0, through Smart Manufacturing and (IoT), D Vuksanović, J. Ugarak and D. Korčok state that "Digitalisation is not a possibility anymore, it is the necessity of the modern world" [30].

3.1. Digital Innovation

J.A Schumpeter first conceptualised innovation in 1912. He is the founder of 'creative destruction' concept, which is the continuous destruction of old concepts to make way for the development of new ideas. He described innovations as [31]:

- Developing new products
- New methods of production
- Opening a new market
- Acquiring new materials
- A new organisation of processes

Process Innovation is described as “performing an activity in a radically new way”, it is usually explained by the adoption of new technology alongside improved business processes [31].

Activities surrounding digitalisation aim to increase productivity, efficiency, and energy savings [30]. Increased use of digital technology requires “Digital Innovation” to change business and production models if these goals are to be achieved.

Digitisation has been forecast to change industries in all sectors permanently although some concerns exist over how this change will come about. Digitisation has the capability to overthrow the current manufacturing industry potentially leading to job losses at every level as robots and automation are introduced [32]. Integrating digitisation into a factory must be done responsibly to ensure that any jobs are not impacted negatively as a result.

3.2. Smart Manufacturing

With the global introduction of digitisation in industry, many manufacturing companies have started to utilise new technologies and methods. This has led to ‘Smart Manufacturing’, which is becoming the central manufacturing technology for the 21st century [33]. Smart Manufacturing combines manufacturing with digital technologies to derive knowledge from raw data [34]. Such collaboration can create highly customizable products to optimise a range of factors including cost, quality, lead time and environmental impact. Data is collected from sensors during manufacturing and used to bridge the gap between the supply chain and the engineering organisation [30]. The purpose of Smart Manufacturing is to optimise production by implementing ICT and advanced manufacturing technologies. Using decision-making models with intelligent devices and data analytics, the entire life cycle of a product can be facilitated [34].

3.3. Industry 4.0

The first industrial revolution in the late 18th century, represented by the mechanisation of manufacturing, was powered through water and steam [35]. This introduced the first transition from manual labour into manufacturing processes mostly in the textile industry [36].

The second industrial revolution occurred in the early 1900s, triggered by electrification, which introduced industrialisation and the concept of mass production. Henry Ford who mastered this, is famously quoted to say "you can have any colour, as long as it is black" which was in regards to the large scale production of the Ford T-Model. The car was manufactured on a moving assembly line as a standard design with no variations, so black was the only colour available [37].

The third industrial revolution came in the 1970s with the introduction of digitalisation through micro-electronics and automation. This allowed for flexible production in manufacturing, as factories now contained programmable production lines [36]. The progression of industrial revolutions is described below in Figure 3.3-1.

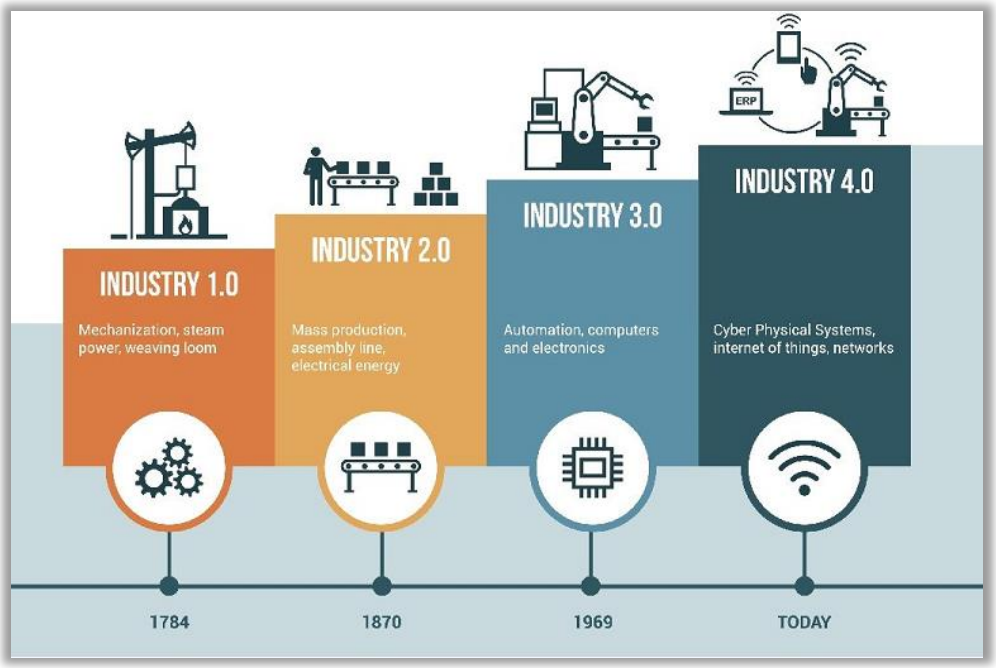


Figure 3.3-1 The history of Industrial Revolutions [38]

Industry 4.0 is described as the fourth industrial revolution, representing control and organisation across the entire life cycle of the product, resulting from the development of Information and Communication Technologies (ICT) [36] [39]. Industry 4.0 aims to encourage factories to employ competitive advantages such as 3D printing, robotics and other features of manufacturing that this revolution supports [40]. Future factories are assumed to be intelligent, with the ability to self-plan and self-adapt, using a completely digital product model to meet the needs of customers and logistics of the supply chain [31]. The objective of Industry 4.0 is to improve the efficiency of operations while increasing automation of manufacturing processes to move product to market swiftly [35].

Industry 4.0 is based on employing continuous improvement strategies and integrating humans into the manufacturing process. Another focus is on value-adding activities, achieved by avoiding wasteful actions. The aim for Industry 4.0 is to make machines 'self-learning' to improve performance and efficiency, and will transform manufacturing into a fully digitised and intelligent process [39]. Industry 4.0 aims to have a continuous flow of information between devices, known as Machine-to-Machine (M2M) interaction. This interoperability and connectivity are two of the most important elements of Industry 4.0, which can be achieved by implementing the Internet of Things (IoT) [36].

3.3.1. Internet of Things

The concept for the IoT was first coined in 1999 by Kevin Ashton and describes a system where the material world exchanges data through sensors with computers. The first iteration of IoT was involved with Radio Frequency Identification (RFID), which was used for identification and tracking of items in the Proctor and Gamble (P&G) supply chain [41]. Ashton explained that the term was intended to describe the connection between humans and computers. His view was that the latter are 'dependent' on humans for information, which is recorded through scanning barcodes, taking photos or entering data by typing. IoT records information about our environment, and by empowering computers to gather information without human interaction, it is possible to track and count everything, providing insights into when repairs or replacements are necessary and reduce waste and improve efficiency [41].

Since the uptake of this concept began, it has also been referred to as the 'Internet of Everything' due to the vast number of devices connected. This approach connects processes, people, devices and machines [31].

There are three vital features of IoT:

- Context
- Omnipresence
- Optimisation

Context allows any object to provide information, such as location or condition. Omnipresence describes the future communication capability of each connection; it describes how vast IoT is. Optimization is the "expression of the functionality which every object possesses" [31]. IoT supports the development of Industry 4.0 as it promotes the connection of devices, machines, and processes via the internet. This allows for communication between processes and can be used in 'Smart Production' to control production lines through automation [31] [30]. Industry 4.0 is the digitisation of manufacturing by utilising IoT for communication and information sharing [42].

3.4. Policy for Industry 4.0

Germany first introduced the concept of Industry 4.0 in 2011 as a strategic initiative to support the digital transformation of the German industrial sector [42]. The 'High-Tech Strategy 2020' action plan was announced in 2011 to focus on the development of cutting-edge technologies [43]. In doing this, Germany has cemented itself as one of the leading countries for manufacturing [36].

In response to this, France announced 'La Nouvelle France Industrielle' in 2013, which defined the French priorities for policy aimed at the re-industrialisation of France [43]. France announced the concept 'Industrie du Futur' in 2015. This concept is based on industrial cooperation and was intended to be the core of industrial policy in the future of France. This initiative involved five pillars [36]:

1. Cutting edge technologies including additive manufacturing, virtual plant, IoT, and augmented reality

2. Supporting the French companies, especially small to middle-sized ones, to adapt to new technologies
3. Extensive employee training
4. Strengthening international cooperation around industrial standards
5. Promotion of French industry of the future

The European Commission announced ‘Factories of the Future’ in 2014, this is a Public-Private Partnership, under the Horizon 2020 program. The aims for this initiative are to strengthen and improve “industrial competitiveness and sustainability via research and innovation in new production technologies and systems” [44]. This initiative has encouraged companies to invest in projects that will help their organisation align with the goals for Factories of the Future (FoF). The main goals outlined in the official document for FoF include [44]:

- Integrating and demonstrating innovative technologies for advanced manufacturing systems,
- Moving towards environment-friendly manufacturing and increasing EU industrial competitiveness,
- Sustainability through the development of new knowledge-based production technologies and systems.

The FoF initiative is intended to work with the Europe 2020 strategy which aims to address employment, innovation, education, poverty, and climate change. The goal is to adopt the aims of Europe 2020 through manufacturing; facilitating each one to support economic wealth while minimising environmental impact and empowering a sustainable society [45]. The aims for this plan are outlined in the ‘Factories of the Future Roadmap’, published by the European Factories of the Future Research Association (EFFRA).

China moved to develop a similar plan, ‘Made in China 2025’ which was introduced in 2015 and was introduced in cooperation with the China Ministry of Industry and Information Technology alongside industry experts. The plan aims to upgrade the Chinese manufacturing industry, taking inspiration from Germany’s original Industry 4.0 initiative, adapted for the needs of China. The goal was to move China’s manufacturing industry from producing large

amounts of low-cost items to producing better quality goods using sustainable development and green energy innovations [36].

Similar policies have also been introduced in the US, UK, South Korea, Japan, and Singapore. This global increase in initiatives aiming to improve manufacturing through innovation shows how popular this research area has become. Investing time and money into digitising processes to introduce Smart Manufacturing will be beneficial to both the company and the economy on a national scale. Introducing Smart Manufacturing will align a factory with the targets set out by Industry 4.0, to improve efficiency and create a flexible and automated production process [46].

3.5. Pillars of Industry 4.0

Industry 4.0 is made up of nine pillars, which can be applied to transform various aspects of manufacturing. These nine pillars are discussed below.

3.5.1. Big Data and Analysis

Collecting data from machines and processes is crucial for improved, real-time decision making. Big Data provides analysis capabilities that traditional tools could not achieve. This can be used to improve the efficiency of the supply chain [39] [31].

Big Data consists of four dimensions [31]:

- Volume of Data, Big Data describes a dataset which ordinary tools cannot analyse.
- Variety of Data, multiple sources provide a range of unstructured data which are not suited to traditional tools.
- Velocity of the generation of new data and analysis, Big Data analysis is carried out in near real-time speed to reflect the ever-changing supply of information.
- Value of Data, Big Data aims to isolate relevant information from actual results.

Data analysis can be performed on historical logs to uncover and investigate any recurring issues from the past. Furthermore, this information can be used to forecast any future issues

that may be encountered [39]. Big Data allows for rapid and efficient management of data, which is continually growing as a result of IoT and information sharing from multiple sources. Analysis supports the separation of essential data from that which is less useful to the production process. By using this, conclusions can be drawn which support improved decision making and knowledge transfer [31].

3.5.2. Autonomous Robots

Industrial robots have evolved to become more flexible and versatile; they have become key players in adding value to factories and assisting with Industry 4.0. Robots can complete tasks intelligently, focusing on [42]:

- Safety
- Flexibility
- Versatility
- Collaboration

Robots can provide autonomous mobile support for repetitive actions on a factory floor, moving between machines carrying parts or tools, as necessary. Automation can be used to reduce human labour through the restructuring of the work process and introduction of a robot which can assist in manufacturing [10]. Autonomous robots can be used in place of humans in dangerous or restricted areas, or situations when precision is vital [39]. In the future, robots will work alongside humans in a range of roles, from production to office management [42]. 'Collaborative robotics' describes when humans work together with robots to execute complex tasks. This is known as Human-to-Machine (H2M) and is used in place of M2M for tasks that are too unstructured to be completely automated [36].

There are some robots already available for use in factories, such as the Kuka LBR iiwa. Iiwa means 'intelligent industrial work assistant'. This robot is designed for close cooperation on sensitive tasks, documenting the work being carried out, and it has the ability to learn from its human colleagues [42].

3.5.3. System Integration

There are three types of integration in Industry 4.0 [39]:

1. Horizontal integration, across manufacturing network

   This involves the integration of different agents, business partners, clients, and business models.

2. Vertical integration, networked manufacturing systems

   This involves intelligent production systems, networking smart factories.

3. End-to-end engineering, across the entire product life cycle

   This involves manufacturing and the customer.

Digitally integrating a manufacturing process allows for the automation of communication between machines [47]. Horizontal and vertical integration allows factories to assimilate with various departments, in addition to companies and customers. This creates a 'data-integration network' for the manufacturing process [42].

3.5.4. Industrial Internet of Things

The Industrial Internet of Things (IIoT) is considered to be the integration of the physical manufacturing world with its digital counterpart, combining Big Data analytics with IoT [33]. IIoT assists the production stream in becoming intelligent through sensors and data, allowing machines, products, and factories to communicate [36] [39].

3.5.5. Simulation

Simulations are used to mirror physical processes in a virtual setting; this is known as a 'Digital Twin' (DT) [46]. The concept of DT was first introduced by Michael Grieves in 2003 [48]. Real-time data is used to create a virtual model of machines and processes to simulate behaviour in a real-world setting and provides feedback with results. This allows DT to predict and detect issues with physical parts through simulations [48]. DT can be used to assist decision making through real-time communication between machines, sensors, and humans [42] [46]. These models can be used for mapping out machines on factory floors, which lessens setup

times during a physical changeover, in addition to providing insight into energy consumption and cycle times [39].

Cyber-Physical Systems (CPS) are multi-dimensional systems that combine computing, communication and data storage to monitor and control the physical world [49]. The term was christened in 2006 by Helen Gill, as she endeavoured to describe complex systems that IT terminology could not illustrate [50]. CPS can work autonomously, using microcontrollers and sensors to interact with their production environment. It is similar to IoT, however, CPS utilises more coordination between physical and computer elements [47]. CPS have been described as the basis for the upcoming industrial revolution as they signify the connection between machines and entities in the physical world. Cyber-physical integration is the basis of Smart Manufacturing. Feedback loops provide access for physical processes to affect cyber parts [48].

DT and CPS both have similar features that assist with manufacturing. They are both intertwined with learning from machine data through sensors via an internet connection. DT is a concept that is more involved with simulation and diagnostics rather than live control of physical entities. CPS use real-time data to make decisions regarding the control of physical entities. Both concepts are essential features of Industry 4.0 and Smart Manufacturing and can be used to present solutions to optimise manufacturing [48].

3.5.6. Cyber Security

As Industry 4.0 utilises the internet to share data between processes and intelligent machines, this increase in connectivity and data sharing requires protection against cybersecurity threats [42]. The introduction of Cyber-Physical Systems (CPS) systems also require cybersecurity as they are systems that integrate computation, communication, and control [39].

3.5.7. The Cloud

Cloud-based platforms are vital for connection and communication between multiple sources, such as machines or processes. With the improvement in information sharing and machine automation in Industry 4.0, increasing amounts of data will be deployed to the cloud. This will result in an increase in data sharing within factories and across sites globally [42].

3.5.8. Additive Manufacturing

Additive manufacturing can be widely used to produce small batches of products, customised to a customer or consumer needs. These designs are usually small, lightweight and can be complex. Additive manufacturing can be used in conjunction with a rapid prototyping method such as 3D modelling and printing [36] [30]. Using this method of manufacturing can be quicker and cheaper than traditional methods, improving production lead time [39]. This method can be used with a range of materials such as plastic, metal, and concrete [51].

3.5.9. Augmented Reality

Augmented reality (AR) can be used in various aspects of manufacturing. It is usually utilised through an AR headset. This headset can provide live maintenance information from a subject matter expert (SME) to an employee to fix an issue with a machine. It can also be used to track and select parts in a warehouse [39].

3.5.10. Summary of Industry 4.0

The pillars of Industry 4.0 have been discussed in this chapter. Diving into each aspect has shed light on how these features are currently used in production to improve processes through digitisation and automation. These insights can provide inspiration for this research, and how any output or proof of concept could be used.

An important feature of Industry 4.0 that can be aligned with this research is Big Data and Analysis. This strand of Industry 4.0 focuses on sorting data and removing anything that is not useful. Another facet of this is data analysis, investigating historical data to reveal any trends in issues that have been encountered. Data management is a crucial part of this feature, as IoT naturally results in vast quantities of information from many sources. Data management should be a priority for any production process, to organise any relevant information that can improve it.

The learnings from Industry 4.0 will be applied to the development of this research, with the aim of improving efficiency and streamlining processes.

3.6. Digitisation in Other Industries

Digitisation of manufacturing processes must be carried out to implement Industry 4.0 and IoT. Research has been completed to investigate how digitisation is used in factories today. As discussed in Chapter 3.5, there are various aspects of Industry 4.0. This means that there are many different ways that companies can employ it within their factory. Examples of digitisation include [51]:

- Scanning
- Measuring
- Automation
- Simulation

The three industries that are considered in this research are manufacturing, construction, and aeronautics. These industries have been selected as they can be used as an indication of current methods and trends of digitisation across multiple industries. However, manufacturing is of most importance for the development and implementation of this research.

3.6.1. Digitisation in Manufacturing

As manufacturing companies globally have begun to move towards Industry 4.0, many have started to utilise Smart Manufacturing through digitisation.

M. Helu and T. Hedberg present a product life cycle testbed, which is built on a cyber-physical infrastructure to enable Smart Manufacturing research and development. The methodology proposed allows for the amalgamation of heterogeneous solutions from various points of the life cycle of the product [52]. These data sources combine "enterprise resource planning (ERP), manufacturing execution systems (MES), and quality management systems (QMS)". The purpose of this infrastructure is to reduce cycle time. It will also improve the performance of the process in both product design and manufacturing to bridge the gap between the supply chain and the engineering organisation. The study suggests that experiments may investigate what information is needed in different manufacturing scenarios or processes to further refine the required life cycle information in each phase of manufacturing [52]. If the test-bed is not

brought forward as part of this digitisation project it is still vital to remember the suggestions from the study, that investigation will be required to outline the critical data sources that will be significant in benefitting the manufacturing process.

The concept of knowledge management is brought forward in 'Towards Knowledge Management for Smart Manufacturing'. This paper discusses the need for knowledge capture and management for "quality assurance, lifecycle-impact assessment, and design improvement" [53]. S. C. Feng et al. suggest the main barrier for this is a lack of integration of data and knowledge, through the absence of a well-accepted mechanism to achieve such integration. The three aspects of knowledge management that hold the secret to success in manufacturing are detailed as follows [53]:

- A general context of knowledge in relations to data, information, understanding, and autonomy
- Knowledge that is broken down into units
- Applications of Smart Manufacturing

Implementing these into a factory has the possibility of improving knowledge of the process, and thus improving processing times.

Digitisation in manufacturing presents the concept of knowledge management and finding value in data from the factory floor. Taking this into consideration for the project at hand, the key take away is to have the context to the information available. Furthermore, a clear investigation into what information is most appropriate to include is necessary before developing the final output of this research.

3.6.2. Digitisation in Construction

The breakdown of information management in construction is discussed in 'Modern information management throughout a construction project life cycle – selected issues concerning digitization in construction and a case study' [54]. This paper describes the importance of the link between an organisation's information system and understanding technological changes. As there is so much data required to maintain a factory running effectively, K. Araszkiewicz and A. T. Bojarska suggest standardising information. A few of the suggestions made in this paper to improve ICT solutions include virtual reality (VR), mixed

reality (MR), augmented reality (AR), data exchange and management. This aligns with the pillars for Industry 4.0 discussed in Chapter 3.5. By accessing digital information, K. Araszkiewicz and A. T. Bojarska suggest that this will improve the ability to anticipate and solve issues throughout the product life cycle, which could mean that issues may be tracked and resolved before they cause time-costly issues farther down the line [54].

Building Information Modelling (BIM) creates a virtual model of buildings ahead of construction. It can be used to assist architects, engineers, and constructors (AEC) in the planning, design, and operation of a building. BIM characterises many features of a building's construction plan, including geometry, spatial relationships, material inventories, and project schedule. These features can be used to describe a complete life cycle of a building's construction. BIM is a virtual process that covers all aspects of a construction project, and this makes it easy to outline scopes of work. Using BIM optimises the efficiency, and accuracy of the project, avoiding waste at each stage of construction [55] [56].

D. Bryde et al.'s case study supports the idea of implementing BIM on construction projects [57]. Although this case study is in the context of construction, the benefits of using a fully digitised system are clear. The key areas that saw improvement were cost, time, communication, coordination improvement, and quality. An important note from this paper is the importance of having people involved in using it to adapt current working practices to support BIM [57]. This could mean the inclusion of smart devices and having processes altered to allow for BIM. Case studies presented by S. Azhar all report positive impacts of using BIM, that range from improved building design in response to environmental factors, to money saved by altering plans in the predesign stage of projects [56].

It is important to recognise the risks of BIM, as well as the benefits. An issue with using BIM is determining who takes responsibility for entering and checking any data used. Finding who is responsible when an issue arises can be difficult as BIM blurs the level of responsibility as it is a collaboration between many people. Contract documents regarding ownership should be outlined ahead of the project commencement to avoid any discrepancies. BIM requires computable digital designs, alongside strategies for information sharing between components of the model. A standardised methodology for how to utilise BIM is necessary [56].

The studies presented in this area discuss using standardised information and a fully digitised system. Although it is based in the context of a construction company, the research can still be

applied to a manufacturing company. A fully digitised system can be achieved by improving data exchange and management, including a method of tracking issues to anticipate problems in the product life cycle. The essence of this research is the importance of adapting current processes to align with digitisation through the introduction of technology, such as smart devices including mobile devices. It is important to remember the issues encountered in BIM and bear them in mind during the development of this project. Attention will be paid to outline a methodology for how any process innovations will be managed, along with who will be responsible for updating any information in the proposed project.

3.6.3. Digitisation in Aeronautics

Aeronautics has been specifically chosen as it is a high precision manufacturing industry with lots of data involved, requiring a high level of data management.

JIT manufacturing is a crucial feature in the aeronautics industry, synchronizing procurement and manufacturing activities. This has been achieved by the use of electronic data inter-exchanges, which is the sharing of business documents in a standard electronic format between computers [58] [59]. Flow management is a cumbersome topic in aeronautics efficiency due to the vast number of issues that arise, and the volume of references for information. A case study is presented, which looks into implementing a digital synchronous sequencer to allow for the manufacture of various batches of the product to improve flow management [58]. This sequencer assists in combining the processing of information flow in real-time, and the control of physical flows from beginning to end of the production line. This is introduced for load smoothing, to spread the volume of orders over time by producing smaller batches. The sequencer also aids visualisation and control of all data linked to the production line, which spans from the raw material being supplied through to the transportation of parts for shipping [58]. Furthermore, production information is available in real-time, which provides managers with the opportunity to take rapid measures if required.

T. Hoppe et al. discuss the need for creating a universal data hub in aeronautical manufacturing, as it is a punctilious area with lots of data feedback [60]. In recent years the industry has implemented digitising approaches in the system development processes. A big factor in these meticulous manufacturing industries is digital models of the system development life cycle. These models may include commercial-off-the-shelf (COTS) engineering tools from a range

of vendors, which can lead to multiple domains, paradigms, and file formats. T. Hoppe et al. present the need for developing a system to implement digital models for the whole system life-cycle. To achieve this, a suitable model will be required to represent every aspect of a process, all within the same level of abstraction [60]. Boeing implemented digital prototype technology for the development of the Boeing 777. Implementing this technology reduced the development cycle by nearly 40%, and reduced cost by 25% [33].

The learnings presented from this research area include standardising production data and tracking production throughout the life cycle of the product. A vital aspect of this is to include the data at the same level of abstraction so that it can be combined with other information to provide further insights. It is essential to reflect upon the recurring theme of incorporating a data hub to amalgamate information regarding the production life cycle.

3.6.4. Summary

The background research has described the need for uptake in the digitisation of processes, to align with the aspirations of Industry 4.0. This can be achieved via Smart Manufacturing. To espouse Smart Manufacturing, digitisation of information and digitalisation of production processes must first take place. This will introduce the technology required to access digitised manufacturing information.

Combining the research into Industry 4.0, Internet of Things and digitisation, the apparent outcome is to create a digital information hub to host all relevant data from the production life cycle. The main points from the research into each industry is the importance of having relevant data, presented with context and clear value. Processes should be adapted to allow for digitisation, through the introduction of devices, such as mobile technology. The output from this research should bear in mind the goals of Industry 4.0, to improve efficiency and move towards more environmentally friendly manufacturing processes.

4. Project Outline

4.1. Problem statement

This project involves in assisting a medical device manufacturing company to move towards Smart Manufacturing which can be achieved through digitising information and digitisation of processes. The process focused on is the Pulse Walk, introduced in Chapter 2.9.1. This process has been chosen as it is used across this factory on other Value Streams, and innovating this could have long-term positive effects on many areas of manufacturing in this company.

Pulse Walks are completed three times a day in the manufacturing facility. In one Value Stream, there are five steps to the Pulse Walk; four of these steps allow for discussion with operators to highlight any problems in manufacturing. The map shown in Figure 4.1-1 shows the route of the Pulse Walk. The first step is 'Clean-room, Shipping', and step two is 'Drag, prep, polish'. Step three is 'Low contact stress implants', referred to as 'LCS' and step four is 'Grinders'. Each step covers a range of machines that produce various products, all under the Femoral Implant (FEMs) family – which is a type of device manufactured in this facility. The final step discusses the Key Performance Indicators (KPIs) of the Value Stream so that weekly targets and progress can be tracked.

At each step of the Pulse Walk, there is a whiteboard with a table printed on it. The top section of this table contains a checklist that covers safety, overall equipment efficiency (OEE) and backlog, among other things, shown in Figure 4.1-2. The board also has a section below the checklist that is used to write down problems. Issues are recorded along with the date it was opened, the follow-up action and the task owner, an example is shown in Figure 4.1-3. The issues written on the board are revisited at each Pulse Walk to determine the progress and whether they can be closed. When an issue is adequately dealt with and is closed, it is simply wiped off the board. This means that there are no historical records of issues, and therefore, no way to track if there are any recurrent problems or areas in need of attention. Some boards record between one and eight entries daily equating to anywhere between three hundred and three thousand issues that are not recorded so lost annually across the whole Pulse Walk.

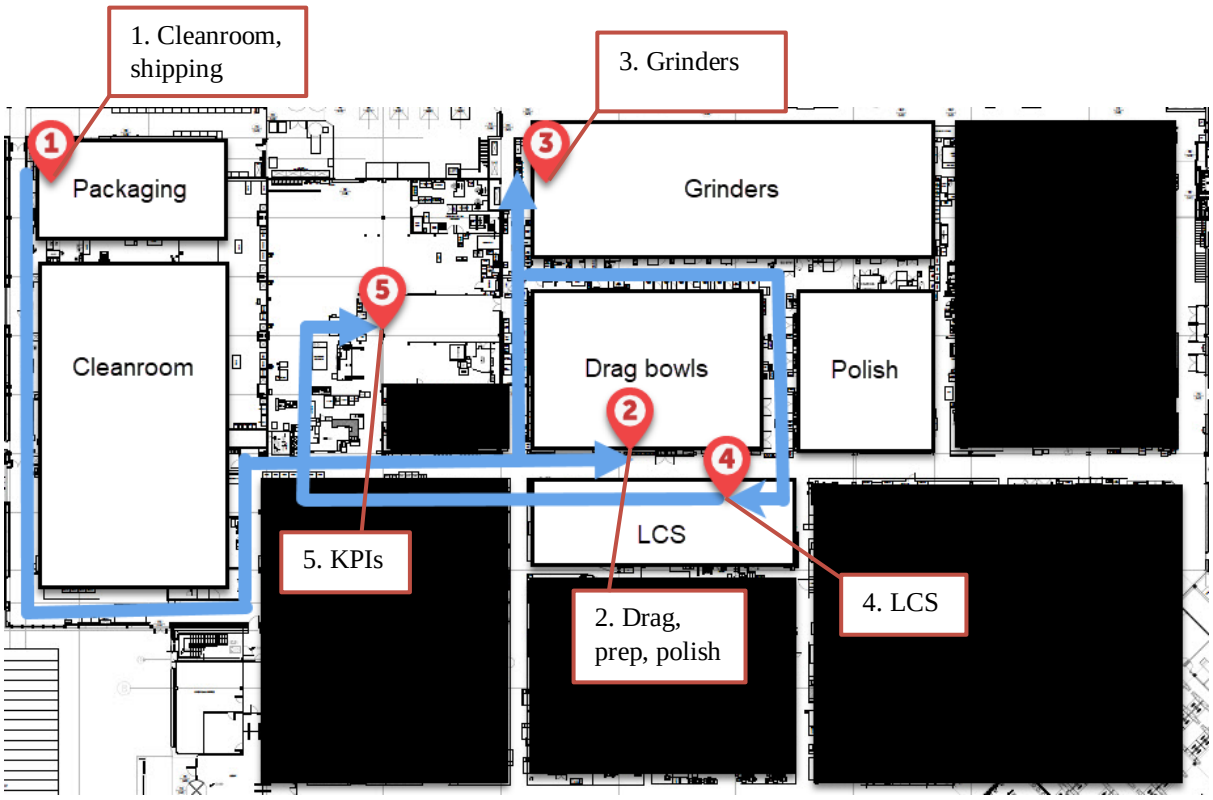


Figure 4.1-1 Map of Pulse Walk for FEMs Value Stream

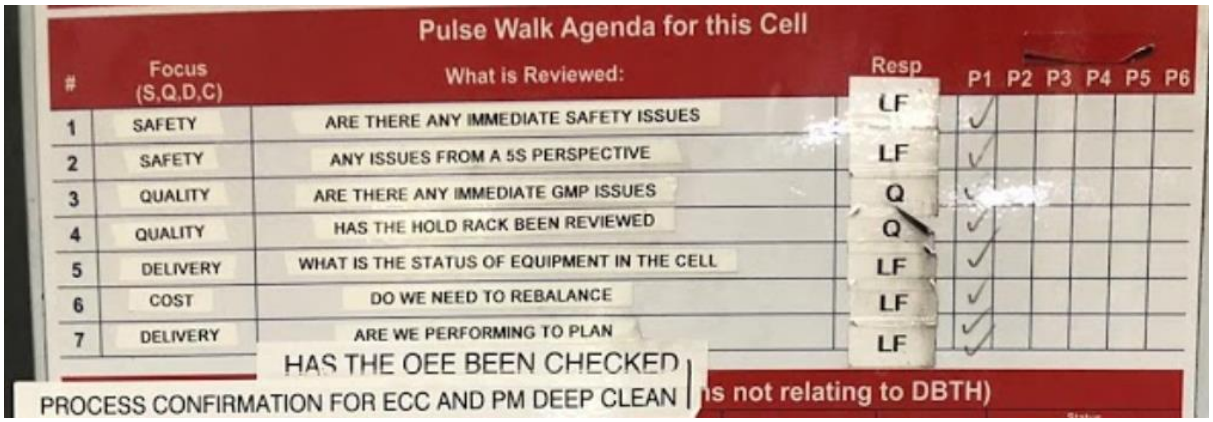


Figure 4.1-2 Checklist on Grinders Pulse Walk board

Workstep	Issue	Action	Owner	Due	Status		
					Open	Closed	Escalated
GRND0054	Probe is broken	Replace	Maintenance	07-Mar-19	06-Mar-19	8-Mar-19	

Figure 4.1-3 Example of Pulse Walk white board table

Other difficulties experienced during the Pulse Walk include high noise levels, which make it challenging to hear discussions of issues and the correlating actions unless the participant is stood adjacent to the person talking. In addition, deciphering written entries on the board can be impeded by the variations of shorthand used to describe departments, machines or tools and as the information is written on a whiteboard, it can be partially erased by accident. Each of the potential human errors outlined creates difficulties in interpreting what is written and in understanding the associated actions.

Other communication challenges include issues raised within the Pulse Walk are shared verbally, so when a manager or Team Lead cannot attend the Pulse Walk, information is not communicated with the rest of the group. This is not an ideal method of knowledge sharing, and also causes setbacks in production and efficiency.

Important information regarding OEE and other manufacturing information is usually printed each morning and attached to the white boards, but to retrieve real-time data means leaving the Pulse Walk to go to a laptop. While these are small and lightweight, the process is cumbersome when the information is required swiftly.

Since the Pulse Walk for this Value Stream usually takes between 40 – 50 minutes, while the desired length timespan is around 20 minutes, there is opportunity to improve the efficiency of the process. The total distance to be walked for the Pulse Walk is 348 metres. The distances between each step are as follows: Step 1 to 2 is 170 metres, Step 2 to 3 is 39m, Step 3 to 4 is 67 and Step 4 to 5 is 72 metres of distance. These distances must be taken into account when including the time taken to walk to each stage. Using an average walking pace of 1.4 metres per second [61]:

- 170m equates to 121.43 seconds, which is around 2 minutes.
- 39m is 27.8, taken as 30 seconds
- 67m is 47.8, taken as 50 seconds
- 72m is 51.4, taken as 50 seconds

The total time spent walking on the Pulse Walk is around 4 minutes and 10 seconds. To take into account a varying paces from those taking part in the Pulse Walk, and time for everyone to congregate at each point this can be rounded up to 5 minutes. The desired length of the Pulse Walk is around 20 minutes, when the time for walking is accounted for this leaves 15 minutes for discussions at the boards. Splitting this across the five boards leaves 3 minutes of discussion at each stage. Achieving this will be a task in itself as the time currently spent at each step can vary a lot. The time spent at one stage can range from several minutes, sometimes up to ten minutes or more depending on the detail of issues being discussed. Improving the speed at which information can be accessed will assist with minimising time wasted at each stage, and could shorten the time required for the Pulse Walk closer to the target of 20 minutes duration.

4.2. Project Aims

This project aims to streamline the Pulse Walk by digitising the Pulse Walk board. A digital version of this board will allow information to be entered rapidly through auto-fill and drop down boxes. Standardising recording of the issues logged will enable data analysis and provide insights into the issues being recorded. This analysis will indicate which work step, machine or tool is causing recurring issues, aid understanding of why the problem has occurred and full repair or replacement to avoid recurrence. To support the digitised Pulse Walk Board, the project will also digitalise the Pulse Walk by introducing technology into the process, discussed in Chapter 4.3.

Optimising information access on the factory floor is the overarching drive for the tool development which will include information from various data sources to assist in manufacturing. This tool aims to improve efficiency, communication and reduce waste as per Lean methodologies discussed in Chapter 2.

4.3. Description of Tool

The aim of this research is to produce a tool that will act as a digital information hub. This hub will include a digital version of the Pulse Walk board with a storage facility to enable access to historical information of past issues. Included in this tool will be access to data sources that will assist in manufacturing available through scanning a QR code on a company-issued iPad, described in Figure 4.3-1. This will open a menu page with options to access manufacturing information from the selected data sources, or the digitised issue logging table.

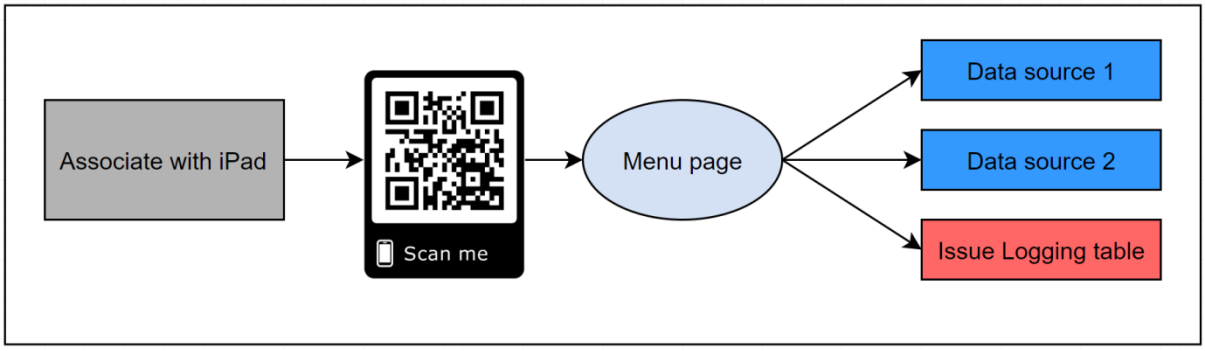


Figure 4.3-1 Tool structure

There will be one QR code for the Value Stream. The QR code will be positioned around the Value Stream at various locations along the Pulse Walk, highlighted in green below in Figure 4.3-2. This diagram explains how the QR code will provide access to the different data sources, highlighted blue, which will be available every time it is scanned on an iPad. The options shown here are a range of data sources used in the factory and could be included in the tool. The data sources will be discussed further in Chapter 4.6.

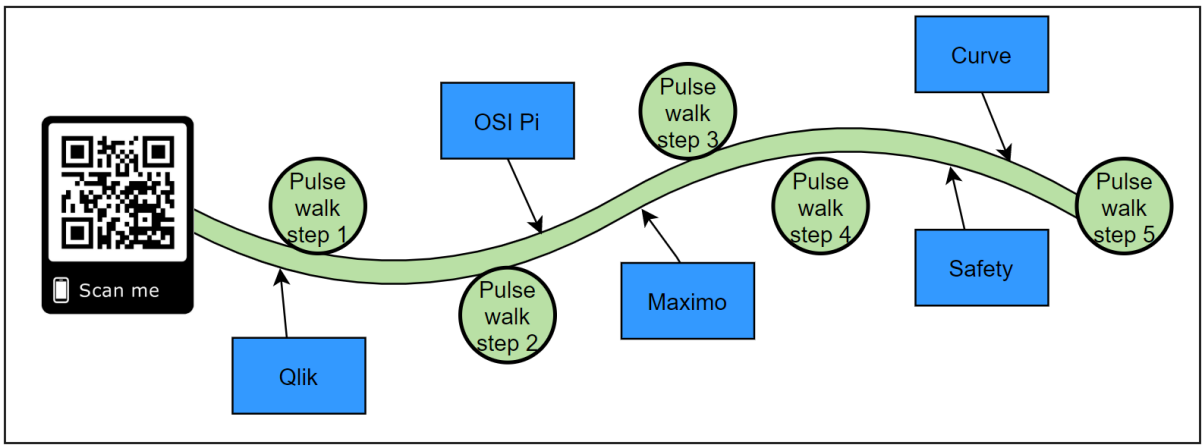


Figure 4.3-2 QR code position in Value Stream

This tool will be referred to as a 'Digitised Manufacturing Information Nexus' (DMIN), as it will be a hub for various aspects of manufacturing information, including issue logging and tracking.

4.4. Methodology

In order to make this project a success, it will require a structured approach that allows the associate and engineers that will be interacting with it to accept and understand how to use it appropriately and successfully [2]. Time has been taken to work alongside staff involved in the Pulse Walk to get their feedback and advice throughout the development of this project and subsequent tool. The methodology utilised for this research is discussed below in Figure 4.4-1.

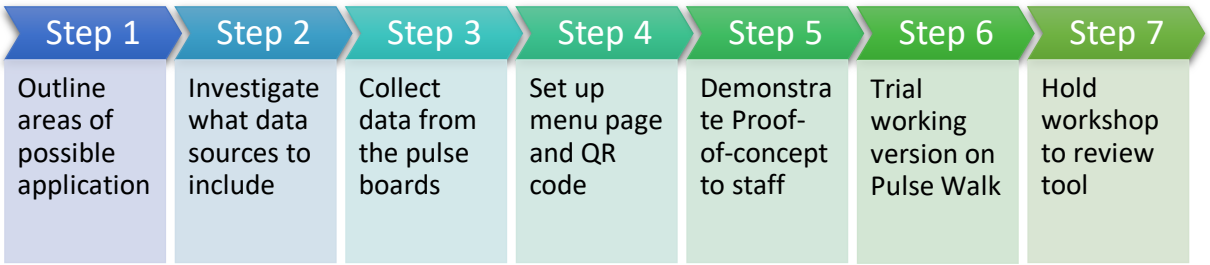


Figure 4.4-1 Methodology used for project

Step 1: Outline areas of possible application

For this research to be most effective, it is crucial to investigate the most useful and appropriate area of application for the work. To do this, time was spent learning about the Pulse Walk process and the factors involved in it. Multiple Pulse Walks were attended in the initial stages of the project, which provided an experience of the process in action. Any problems or inconveniences involved in the Pulse Walk process were noted; these are explained in Section 4.1. By incorporating the background research into digitisation discussed in Chapter 3, the decision was made to innovate the whole Pulse Walk. The idea of creating a tool that could be used for data access and issue logging was formulated.

Step 2: Investigate what data sources to include

As there are many data sources involved in the manufacturing process, it was essential to determine the most beneficial to include as part of this research. To do this, a survey was sent out to everyone involved in Pulse Walk of the selected Value Stream to get their opinions on what would be useful information to include as part of the project. This was a simple online survey that asked how likely the person would be to use the product, and what data sources they would like to see included. This survey is discussed in Chapter 4.5.

Step 3: Collect data from the pulse boards

As the issues logged on the Pulse Walk are deleted when they are completed, it was imperative to begin to collect the information from the boards. This collected data was used to create a database of real problems that had been encountered. This information was gathered by taking a photo of each board after the morning Pulse Walk. The entries were then recorded in an online Excel Sheet on Google drive, with a separate sheet for each step of the Pulse Walk. This data was recorded in the same way that it was written on the board, an example is shown in Figure 4.4-2. This database allowed some insight to understand better the array of issues being discussed, and to determine the best way to manage the data.

Workstep	Issue	Action	Owner	Due	Status	
					Open	Closed
CS Gauge	missing from cell	[redacted] to get leadtime	[redacted]	08-Mar-19	28-Feb-19	08-Mar-19
Cleanroom	tool (small) 1010595 on seal 0006 side B, crack on top right hand compartment	Update from [redacted], awaiting delivery from Vendor	[redacted]	29-Mar-19	09-Feb-19	
Cleanline	CPSS4003 - leak Tank 1 handed over from night shift	Maximo created for Maintenance	Maintenance	07-Mar-19	07-Mar-19	8-Mar-19
Repack	Sigma PS - Router issue unable to process	Investigate OMS issue to scrap	[redacted]	29-Mar-19	27-Feb-19	

Figure 4.4-2 Online database of Pulse Walk entries

A version of this online database was developed to be used for entering new issues and actions during the Pulse Walk. The original database created from the photos of the Pulse Walk boards was used to outline the 'Issue Codes' used in this new database. This is discussed in Chapter 5.

Step 4: Set up menu page and QR code

As the plan for this project is to create a tool that accesses multiple data sources through the use of an iPad, it was vital to ensure that the information could be retrieved through these means. A demo menu page was set up to test this. It contained the URL of a Pi Vision dashboard which showed real data regarding the OEE of machines on the factory floor. This was successful through the company issued iPad that was connected to the network and had an F5 security app. This is a security measure to ensure they can be granted access before connecting to Pi Vision. The F5 app allows the user to log in with their credentials to connect to the company network on the iPad.

Due to information being accessed from an iPad, it would have been ideal to develop an application for iOS. It was decided to use a dummy menu page for the proof of concept of the tool to expedite this. This consists of a Portable Document Format (PDF) containing hyperlinks embedded into it to connect to the data sources, seen in Figure 4.4-3. This PDF is embedded into a QR code, which will be positioned in the Value Stream to be used to access the information required on the factory floor, as shown in Figure 4.3-2. An online QR code generator was used to embed this PDF [62].

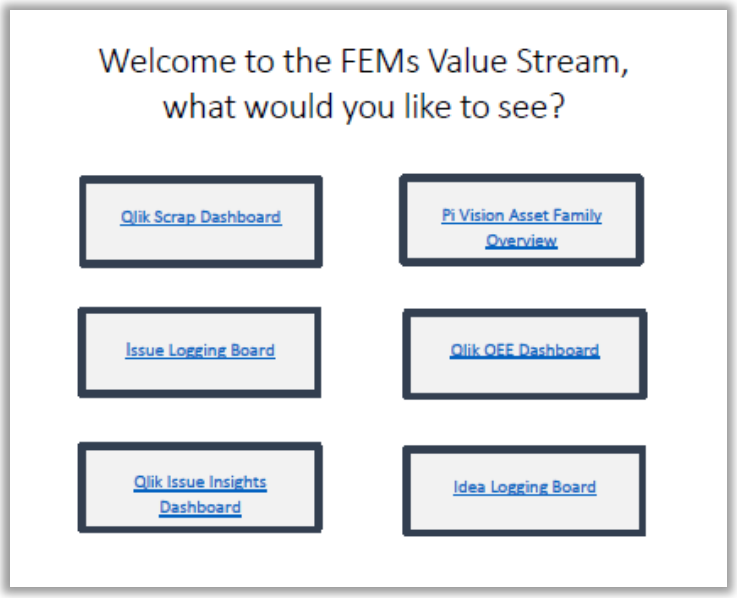


Figure 4.4-3 Finalised menu page for tool used during trial

Step 5: Demonstrate Proof-of-concept to staff

This step involved meeting with staff members who are involved in the Pulse Walk, to explain the proof of concept of the tool. This group of staff included Team Leads, Quality, Maintenance and Operators. The demonstration provided staff with an opportunity to express any feedback regarding the design or functionality of the tool. This was taken on board and used to develop the tool ahead of the trial. This feedback is discussed in Chapter 5.3.

Step 6: Trial working version on Pulse Walk

Following feedback from the previous step, the tool was trialled during the live Pulse Walk to determine the strengths and weaknesses of the product. The tool was trialled at various steps along the Pulse Walk, on iPads and interactive screens. This is further discussed in Chapter 6. This trial will indicate how useful the tool will be if used on the Pulse Walk and identify the areas where it will assist the Pulse Walk.

Step 7: Hold workshop to review tool

A workshop was held at the end of the trial to get feedback from a range of staff members. Each aspect of the tool was discussed, what could be included in any future iterations was

planned. This is discussed in Chapter 6.2. This workshop discussed each aspect of the tool in detail, including hardware, data sources, the issue logging page and data analytics dashboard. The feedback from this was outlined and prepared for future developments of the project to be rolled out on the Value Stream.

4.5. Survey and feedback

A survey was used to garner feedback from those associated with the Pulse Walk. This survey consisted of three short questions that allowed each participant to list their job title, how likely they would be to use the tool presented in this research and what they would like to see shown as part of the tool.

The survey was used as it is a standardised methodology that can be repeated for each participant. This survey provides a quantitative insight into what people would find useful to be included in this project. It also shows the level of interest from people involved in the factory, at various job levels. The structure of this survey was chosen as it is concise and collects the relevant data swiftly. The survey was sent out via a link in an email which explained the preface of the project. This meant that a large group of people could be targeted at the same time.

4.5.1. Question 1

Q1 What type of staff are you?

The first question in the survey asks what types of staff the respondent is. The options include ‘Engineer’, ‘Associate’ and then ‘Other’ with space to describe their role. Associate here refers to operators on the factory floor. This question has given insight into the various types of staff that are involved in the factory floor. It is not as simple as engineer or operator, and each role will have a different focus of interest on what would benefit them from this digitizing project. Including this question means that although the responses are anonymous, individual responses can be tracked. This means that it is clear to see if operators, Team Leads, or any other group of staff members have different opinions or interest in different data sources.

The responses from the first question show that the majority are from engineers. Operators are the smallest number of respondents, shown in Figure 4.5-1. The job roles described in the 'Other' section include Team Leader, Quality, Maintenance, Technician and Planning. This shows the range of staff that are involved in the Pulse Walk, which correlates to a variety of information that could be useful to include.

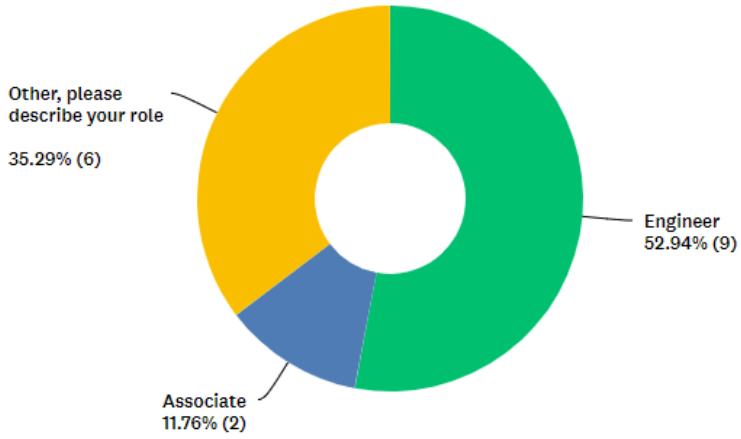


Figure 4.5-1 Survey responses from Question 1

4.5.2. Question 2

Q2 If there was a process implemented on the factory floor that allowed access to information via QR code scanning how likely would you be to use it?

The second question in the survey asks how likely the respondent would be to use the project, with the options ranging from very likely to very unlikely, shown in Figure 4.5-2. This will show how open the employees in the factory are to the idea of digitising information access.

The second question had mostly positive responses, shown in Figure 4.5-2. The respondent who replied that they would be unlikely to use this tool has also indicated that they are an associate, working hands-on with machines on the factory floor. The lack of interest they have shown in using this tool could be based on their concern that it will impede their work. To overcome this, care and attention must be taken to ensure that feedback from all staff is taken on board in order to develop the project into a successful tool that benefits everybody's work. In addition, time must be taken in explaining the goal of this tool and training those into how

to use it successfully. This will show the benefits of implementing the tool and aid in the acceptance of the tool by all staff members.

The two responses for 'neither likely nor unlikely' are from a member of maintenance staff, and a Team Lead. Understandably, maintenance staff may not be interested in this tool, as they are not usually directly involved with accessing data on the Pulse Walk. This data may not be wholly relevant to maintenance staff. However, one of the suggested data sources is Maximo, which is where the work orders for maintenance is stored. If Maximo is included in the tool in the future, maintenance staff should also be trained into how to use the tool as this information could benefit their work. This could lead to a more positive uptake in use from Maintenance as it will aid them, along with relevant information. The Team Lead may also be concerned about whether using this tool on the factory floor may impede productivity or waste time. However, as stated above, attention will be paid to understanding the best way to use this tool to benefit all those involved.

The positive responses are from various job roles, which suggests that this tool could improve many aspects of the production line

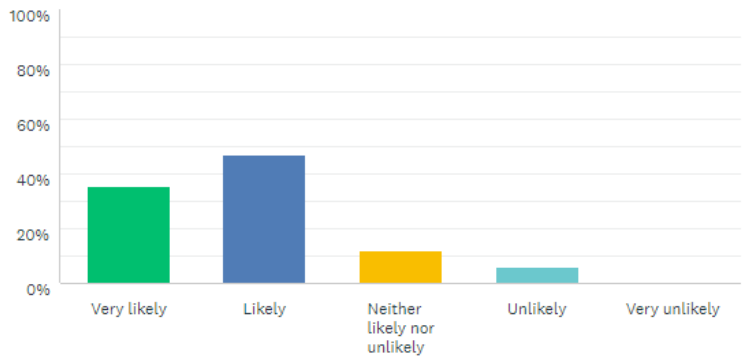


Figure 4.5-2 Survey responses from Question 2

4.5.3. Question 3

Q3 What data sources would be beneficial for your work to include in the QR scanning project

The last question asks which data source would be most beneficial for the individuals work to be included in this project. The options given include OSI Pi, which is visualised through Pi Vision, Qlik, and Maximo along with some others. A description of each data source is

provided in Table 4.6-1. This question also included an option for the respondents to give other examples of data sources they are interested in being implemented. This question gives the respondents a chance to express the data sources that would improve their specific job role.

The last question in the survey asks what data sources should be included that would be beneficial for the respondent. The responses are shown in Figure 4.5-3. The clear front runners are OSI Pi, which will be shown on Pi Vision, and Qlik for scrap dashboards. Maximo is the third most popular option, followed by Curve, Safety and then the other suggestions. These range from energy data, reprocessing information, excess Work-in-Progress (WIP) locations, Material Review Reports (MRR's) in process and Temperature charts for associates. Reprocessing information details any batches that were put on hold for different reasons being reintroduced into the process. The excess WIP locations are where the excess batches on the floor are stored. MRRs in process describe any batches sent back for rework. Temperature charts indicate the location of the associates on the factory floor. Discussions have taken place during the workshop to determine how to access this data and what will be the best way to include the information in the future, discussed in Chapter 6.3.2.

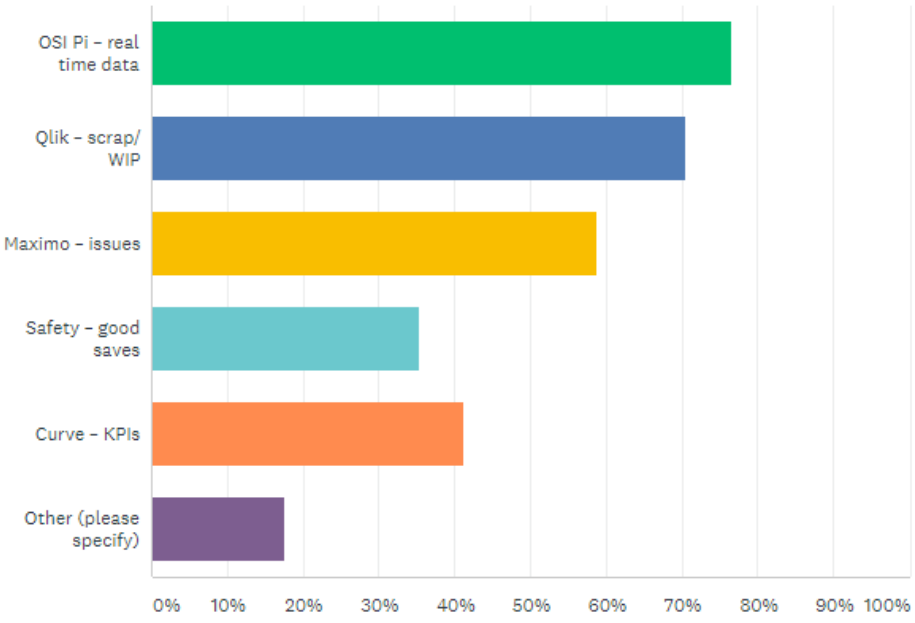


Figure 4.5-3 Survey responses from Question 3

4.6. Data Sources

OSI Pi is useful as it shows real-time OEE data for the entire Value Stream. It can also be used to create other dashboards focusing on the OEE of connected machines. OEE stands for 'Overall Equipment Efficiency' and indicates how efficient the machine is operating. Qlik is used for the scrap dashboard. This dashboard covers all process streams in the factory and can be filtered to show specific data from the chosen Value Stream. For the initial demo of this tool, OSI Pi and Qlik are going to be included as they are the top voted data sources from the survey.

Technical name	*Description*	*% of interest from survey*
OSI Pi	Data historian used to store data from machines - real time data, i.e. Machine status	76.47
Qlik	Data visualization tool, used to create dashboards from historical data, i.e. Scrap	70.59
Maximo	Used to store work orders for maintenance	58.28
Curve	Used to record KPIs from Value Stream	41.18
Safety	Used to record safe work practices, i.e. good saves	35.29
Pi Vision	Used to create dashboards from data in OSI Pi	-

Table 4.6-1 Description of data sources with survey response %

4.6.1. OSI Pi

As it was the highest voted data source to be included, the tool will have an option for accessing OSI Pi data on Pi Vision. This will be through a link on the menu page that will take the user to the homepage for tools in this Value Stream. The user must enter their company credentials to access this page. The user can access the general page, which will show the OEE for each product family, or they can see each machine individually, seen in Figure 4.6-1.



Figure 4.6-1 Pi Vision showing OEE

4.6.2. Scrap Dashboard

Scrap data from Qlik is included in the tool, as discussed above. This is a Qlik dashboard that shows all the scrap data from the entire site. This data can be filtered to show the data relevant to the FEMs Value Stream, for any chosen day, week or month.

4.7. Summary

This chapter has outlined the background of development of the DMIN tool. Following the methodology, the survey was completed and designated that OSI Pi and Qlik were going to be included in the proof of concept to provide access to OEE and scrap data for the FEMs Value Stream. The following chapter will describe the development of the digitised issue log, and subsequent data analytics dashboard that will also be included in the proof of concept for the DMIN tool.

5. Issue Logging and Data Analytics

5.1. Issue logging

Before setting up the issue logging table, research was carried out to investigate existing note-taking applications, to determine whether they would be suitable for this project. Table 5.1-1 outlines the various options below.

Name	iOS	Android	Suitable	Reason
Google Tasks	✓	✓	No	Task-list extension for Gmail, cannot use to make tables [63].
Todoist	✓	✓	No	Task management app, does not support tables [64].
Evernote	✓	✓	No	Organises notes, files and photos but does not support tables with the required features [65].
Wunderlist	✓	✓	No	Shared task management app but no support for tables [66].
Microsoft To-Do	✓	✓	No	Task-list app. No option to make tables [67].
Bear	✓		No	App for recording notes and prose. Editing tools option but no support for tables [68].
Ike		✓	No	Task prioritising app but no support for tables [69].
Noteshelf	✓		No	Records drawn and written notes but no table option [70].

Table 5.1-1 Existing note-taking apps

The options above range from task-list apps that allow users to tick off entries as they are completed. The other type is note recording apps that support sharing information with other users. Each application has been researched to learn what features each possesses. None of the options listed above support table creation, which means that none of the applications can be used, as a personalised table is necessary for the digital replication of the Pulse Walk boards. As a specific table structure is required for the DMIN tool, it has been decided to continue this development through Google sheets, which is an online version of Excel. It allows for tables to be developed and supports most of the features that are standard in Excel, such as drop-down lists and checkboxes. Using Google sheets means that the access for the document can be varied if required, a password can be set up for editing the entries.

The database used to record the issues from the pulse boards, discussed in Chapter 4.4, was developed to be used for entering the issues during a Pulse Walk. This database was set up online using Google sheets. For the sake of this project, the editing features were changed to provide anyone with the URL access. This URL is used on the menu page of the tool, so any staff member using the tool can access this digitised Pulse Walk board and edit it.

The layout of this page replicates the full Pulse Walk whiteboards, including the checklist at the top. These were set up to be checkboxes that could be ticked off after they are conferred on the Pulse Walk, shown in Figure 5.1-1.

PULSE WALK AGENDA FOR THIS CELL

#	Focus	What is Reviewed	Resp	P1	P2	P3	P4	P5	P6
1	SAFETY	Are there any immediate safety issues?	LF	☐	☐	☐	☐	☐	☐
2	SAFETY	Any issues from a 6S perspective?	LF	☐	☐	☐	☐	☐	☐
3	QUALITY	Are there any immediate GMP issues?	Q	☐	☐	☐	☐	☐	☐
4	QUALITY	Has the hold rack been reviewed?	Q	☐	☐	☐	☐	☐	☐
5	DELIVERY	What is the status of the equipment in the cell?	LF	☐	☐	☐	☐	☐	☐
6	COST	Do we need to rebalance?	LF	☐	☐	☐	☐	☐	☐
7	DELIVERY	Are we performing to plan?	LF	☐	☐	☐	☐	☐	☐
8		Parts left at CPS0015 before chem change		☐	☐	☐	☐	☐	☐

Figure 5.1-1 Checklist on digitised Pulse Walk board

Using the database of historical issues, created using the photos of the Pulse Walk white boards, issue codes were outlined to standardise and describe each type of issue encountered. These issue codes are specific to each step of the Pulse Walk and are aimed to be specific enough to target a tool or machine and at the same time be general enough to cover all issues that can arise. The issue codes are used to populate a drop-down option when the cell is selected. This will standardise the issues being logged, and as the cell will start to auto-populate from the list of issue codes, it will improve the speed at which issues can be entered. For example, if there was an issue with the belt on one of the grinders the Team Lead can type ‘Be-’ which will automatically be matched to ‘Belt Issue’. To enter this into the database, they only have to hit the ‘Enter’ key, which will speed up the process instead of having to enter the full words for problems. These drop-down selections are also used to select which work step the issue is concerning, as well as the corresponding action and owners, using word matching for autofill.

The list of work steps has been outlined from historical data and OMS, matching the manufacturing process for parts at each step. The options for owners at each step have been

correlated using the historical data from the photos of the Pulse Walk boards. The corresponding actions have been taken from the same historical data. The options have been combined and standardised to provide a list of general actions for the whole Pulse Walk, alongside specific actions for each step. Examples of these issues and actions are shown in Table 5.1-2

Issue	*Action*
Part damaged	Repair
Part missing	Find
Parts backlog	Review & Prioritise
Tool damaging parts	Investigate
Run one size of parts only	Monitor

Table 5.1-2 Example issue codes with corresponding actions

As many of the real entries from the Pulse Walk boards had more than one owner, a second owner column was added to the sheet. The date columns for each entry have all been formatted to be in "dd-MMM-yy" style. This means that the date can be entered in a range of formats and it will always show in that style. Standardising the format of dates on the sheet will make it easier to follow the chronological order of issues.

With the digitised pulse board implementing a standard set of issues and actions, it is essential to maintain the same degree of accuracy that can be achieved on the whiteboards currently used during the Pulse Walk. A 'Notes' column was added to the sheet to avoid losing details for issues. This column is used for entering any further information regarding an issue that would otherwise be missed. An example of this is shown below in Figure 5.1-2. The issue indicates that parts are uneven at Grinder 46. The notes section provides the details of which type of part is damaged.

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes
						Open	Closed	Escalated	
GRND0046	Parts uneven	Manual load	Operations		8-Mar-19	7-Mar-19	9-Mar-19		Sigma PS 3L part's uneven

Figure 5.1-2 Example of digitised issue log entry

Figure 5.1-2 also shows the filter option in use, the column on the right has a filter icon highlighted. This indicates that a selection has been made. A filter option is available for each column, which means that the data can be selected and filtered by each data constraint such as Issue, Action or Owners. This makes it easy to show which issues are currently open, by selecting the filter option for the Status, Closed column and selecting the 'Blank' values as no closed date has been entered for any open issues. This facilitates the Pulse Walk by showing only the open issues, as it would be on the whiteboards that are currently used.

Using the dates entered for each issue – the open, due and closed dates – calculations can be performed to show more information for each sheet. A column for calculating lead time, and days overdue has been added to the board. The Lead Time column calculates the difference between the issue open and close date. The Days Overdue column calculates the difference between the closed and due date.

These are used to calculate the Average Lead Time and Average Days Overdue for issues at each step of the Pulse Walk. The calculations for Average Lead Time, Average Days Overdue and Number of Issues (open and closed) have been added to the sheet, as shown in Figure 5.1-3.

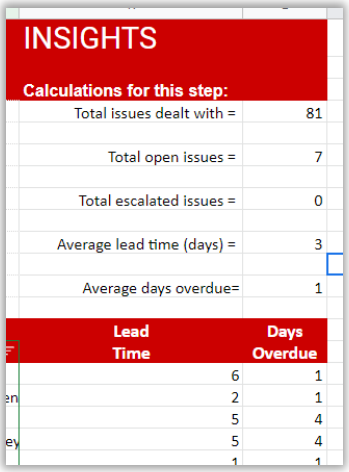


Figure 5.1-3 Calculations for issues

The calculations added to the issue logging board have been used to assist in the data analytics, which is discussed in the next section.

Figure 5.1-4 shows the digitised issue logging board, with each aspect that has been discussed in this section. The entries from the database created with the photos of the Pulse Walk boards have been stored in this format. This means they can be included in any data analysis.

PULSE WALK AGENDA FOR THIS CELL — INSIGHTS

#	Focus	What is Reviewed	Resp	P1	P2	P3	P4	P5	P6	Calculations for this step:	
1	SAFETY	Are there any immediate safety issues?	LF	☐	☐	☐	☐	☐	☐	Total issues dealt with =	80
2	SAFETY	Any issues from a 6S perspective?	LF	☐	☐	☐	☐	☐	☐		
3	QUALITY	Are there any immediate GMP issues?	Q	☐	☐	☐	☐	☐	☐	Total open issues =	7
4	QUALITY	Has the hold rack been reviewed?	Q	☐	☐	☐	☐	☐	☐		
5	DELIVERY	What is the status of the equipment in the cell?	LF	☐	☐	☐	☐	☐	☐	Total escalated issues =	0
6	COST	Do we need to rebalance?	LF	☐	☐	☐	☐	☐	☐		
7	DELIVERY	Are we performing to plan? Scrap? OEE?	LF	☐	☐	☐	☐	☐	☐	Average lead time (days) =	5
8		Process confirmation for ECC and PM deep clean?		☐	☐	☐	☐	☐	☐		
										Average days overdue=	1

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes	Lead Time	Days Overdue
						Open	Closed	Escalated			
GRND0048	Msuite issue	Monitor	Engineering	Maintenance	7-Mar-19	2-Mar-19	8-Mar-19			6	1
GRND0054	Probe issue	Replace	Maintenance		7-Mar-19	6-Mar-19	8-Mar-19		probe broken	2	1
GRND0072	Loading / Unloading Issue	Adjust	Maintenance		7-Mar-19	6-Mar-19	11-Mar-19			5	4
All grinders	Part issue	Fix	Maintenance		7-Mar-19	6-Mar-19	11-Mar-19		Blue allen keys are all rounded a	5	4
GRND0079	Dress Wheel	Fix	[redacted]		7-Mar-19	7-Mar-19	8-Mar-19			1	1
GRND0046	Parts uneven	Manual load	Operations		8-Mar-19	7-Mar-19	9-Mar-19		Sigma PS 3L part's uneven	2	1
All grinders	Test changer blocks	Monitor	[redacted]		7-Mar-19	7-Mar-19	8-Mar-19			1	1
GRND0046	Parts uneven	Manual load	Maintenance		11-Mar-19	8-Mar-19	12-Mar-19		Sigma PS 3L low on anterior	4	1
GRND0095	Probe issue	Replace	Maintenance	Engineering	11-Mar-19	8-Mar-19	12-Mar-19			4	1
GRND0049	Manual lead	Order	[redacted]		21-Mar-19	8-Mar-19	21-Mar-19			13	0
GRND0059	Dress Wheel	Replace	Engineering	[redacted]	11-Mar-19	11-Mar-19	12-Mar-19			1	1
GRND0076	Pipe work loose	Fix	Facilities		12-Mar-19	12-Mar-19	13-Mar-19			1	1
GRND0060	Door Issue	Fix	Maintenance		12-Mar-19	12-Mar-19	14-Mar-19		Main door not opening or closin	2	2
GRND0072	Loading / Unloading Issue	Investigate	Maintenance		14-Mar-19	12-Mar-19	15-Mar-19			3	1
GRND0059	Airflow issue	Adjust	Facilities		15-Mar-19	12-Mar-19	15-Mar-19		high airflow over head	3	0

Figure 5.1-4 Snippet of full digitised issue logging board

This style of digital issue logging board has been applied to steps one to four of the Pulse Walk. The KPI board has been separated into ‘KPI Issues’ and ‘KPI Actions’. These sheets are going to be kept as free text as the issues cover an extensive range, making it challenging to create a standardised set list of options.

5.2. Data Analytics

One of the aims for this project is to use historical data to highlight recurring issues or problematic areas. To do this, data analysis needs to be performed on the data that has been collected. The entries logged into the digitised issue logging page have been extracted and copied into an Excel document. Each step of the Pulse Walk was separated into sheets. This document was used to create a dashboard on Qlik, with a range of graphs describing the relationship between issues, work steps, owners and lead time. These charts will be discussed below.

In the following pictures, the Grinders stage of the Pulse Walk has been chosen. The widgets shown in Figure 5.2-1 indicate the number of issues altogether, and the amount open and

closed. This is followed by the average lead time of issues. These values are taken from the lead time calculations on the Issue Logging table, mentioned previously in Figure 5.1-3. The open and close dates for each issue are used to determine if it has been closed, and calculate the lead time.

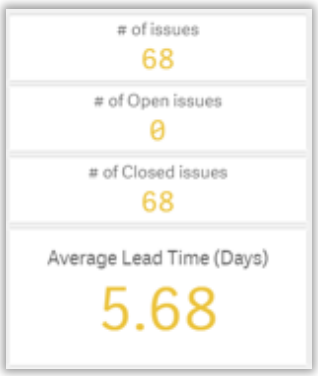


Figure 5.2-1 Issue count widgets

Below, in Figure 5.2-2, the left graph details the amount of issues at each work step as a bar graph. The pie chart on the right shows the percentage split of the number of issues per work step.

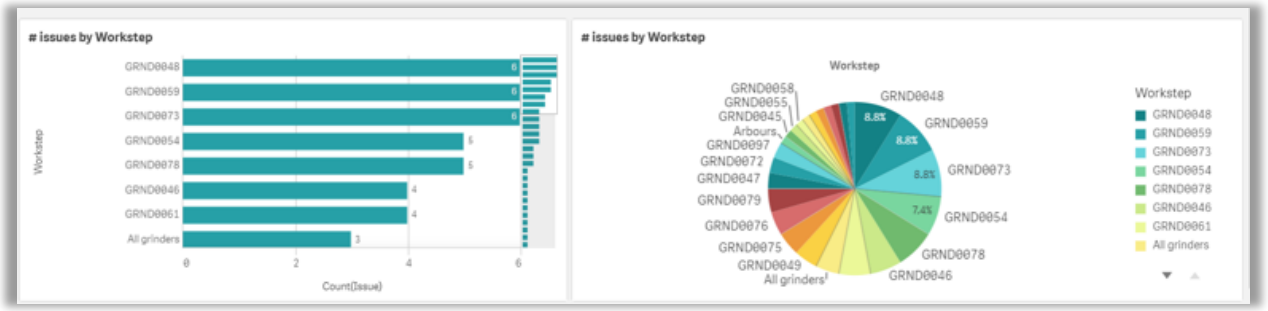


Figure 5.2-2 Graphs showing Number of Issues per Work step

Figure 5.2-3 shows a donut graph, which illustrates the percentage split of lead time per work step. This graph indicates which work step has the longest average lead time to deal with associated issues. This graph will highlight where the most time is being spent to rectify issues.

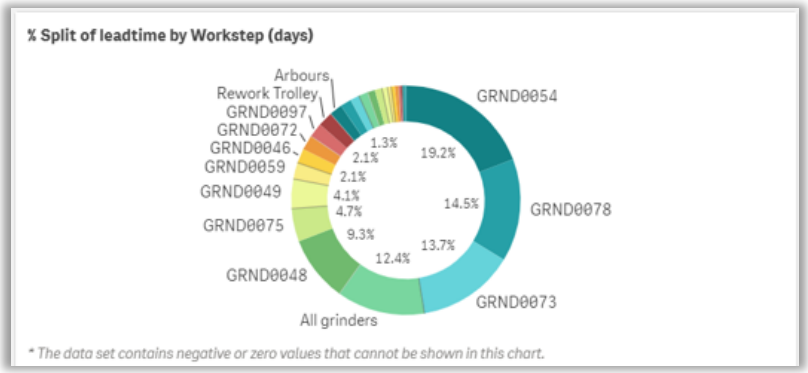


Figure 5.2-3 Percentage split of lead time by Work step

The next section of the Issue Insight dashboard contains a graph showing the amount of each issue, and the details table seen in Figure 5.2-4 . The bar chart "# of issues" indicates which is the most prevalent, for the Grinders step we can see that Arbour and Part issue are the most common problem encountered. The details table on the left is scrollable and shows each column from the excel sheet.

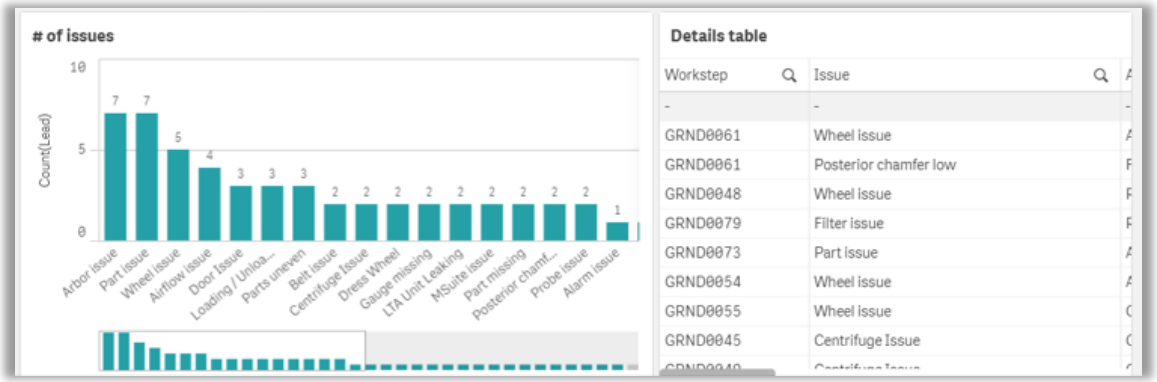


Figure 5.2-4 Number of issues and details table

The graph on the left of Figure 5.2-5 shows the lead time for each work step in days. This is similar to the donut chat in Figure 5.2-3, but instead shows the information in a horizontal bar chart. "Total lead time by Owners" on the right of Figure 5.2-5 shows the lead time by each owner. The owners are a mix of departments and individuals, it is clear that Engineering have the longest average lead time for dealing with issues.

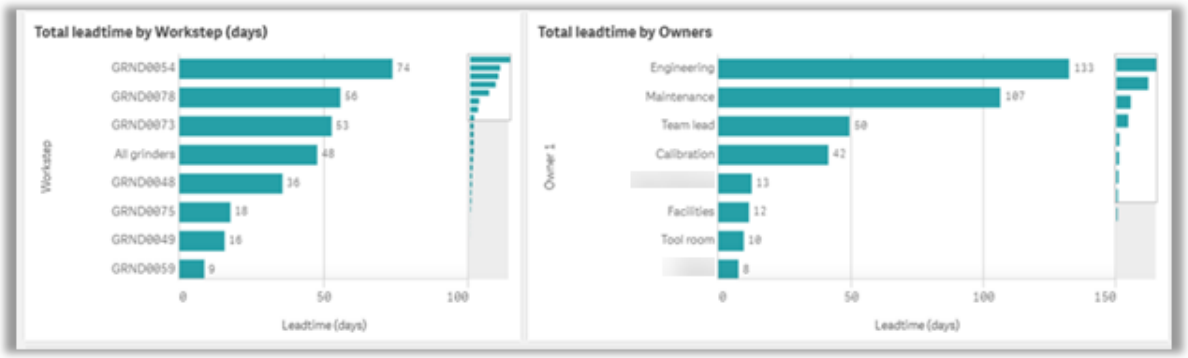


Figure 5.2-5 Lead time by Work step and Owners graphs

The graphs in Figure 5.2-6 details the number of issues for each owner, combined with the lead times. This will show which owners have the most prolonged lead time rate per issue. The first graph shows this chart for the whole Value Stream, we can see the shaded bars show the range of lead times for issues for each owner. The second chart shows this chart for the Grinders step. It does not contain any shaded bars as each owner only has one issue each, and therefore there is no range of lead times to highlight.



Figure 5.2-6 Issue Count per owner with lead times

Figure 5.2-7 shows the layout of the full dashboard, including each chart that has been discussed in this section.

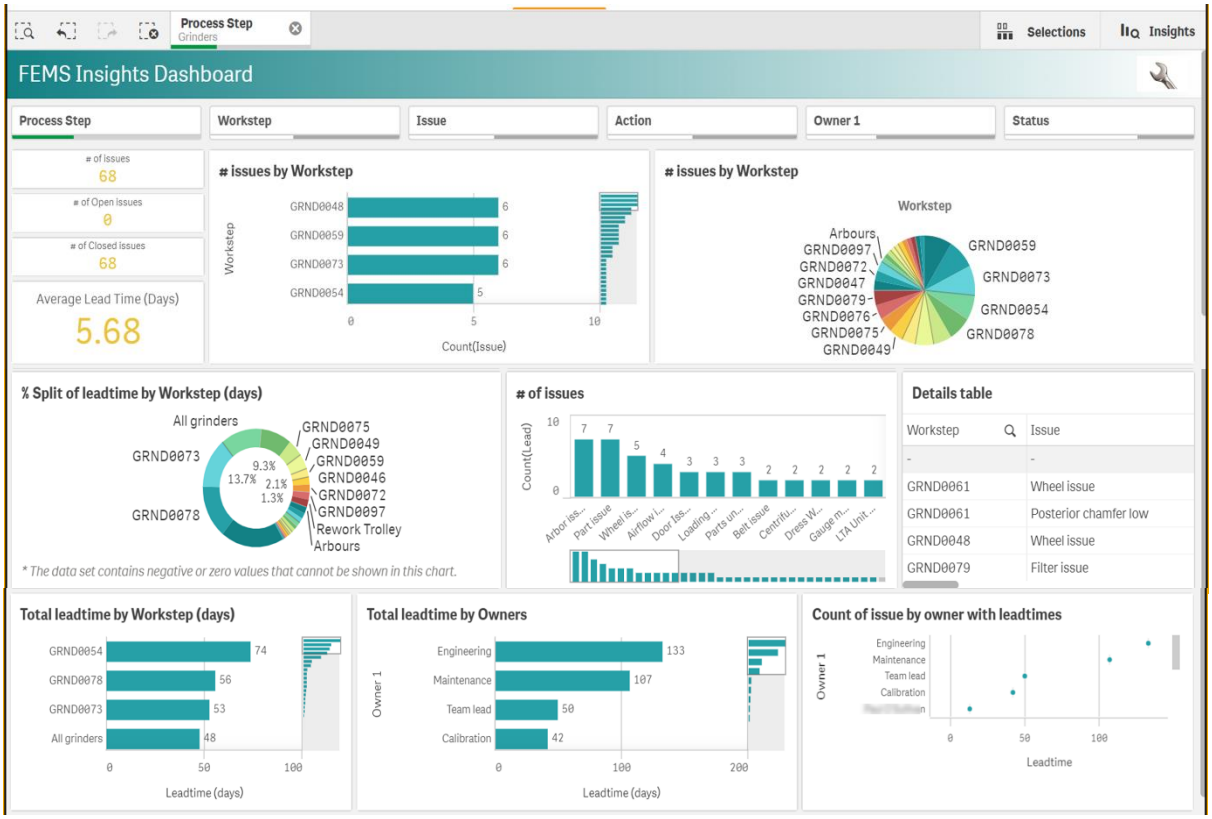


Figure 5.2-7 Layout of Issue Insight dashboard

Qlik was chosen to use as a platform for this dashboard as it is already in use across the medical device manufacturing company, so staff are familiar with the functionality of the software. A feature of using Qlik is that if a user would like to filter by any data constraint, they can select it on any graph. This will highlight it, and then filter the remaining graphs to show the information in relation to the selected data. An example of this is shown in Figure 5.2-8. GRND0048 has been selected from the graph in the middle of the top row. This has triggered the rest of the charts to update only to show the information relating to this machine.

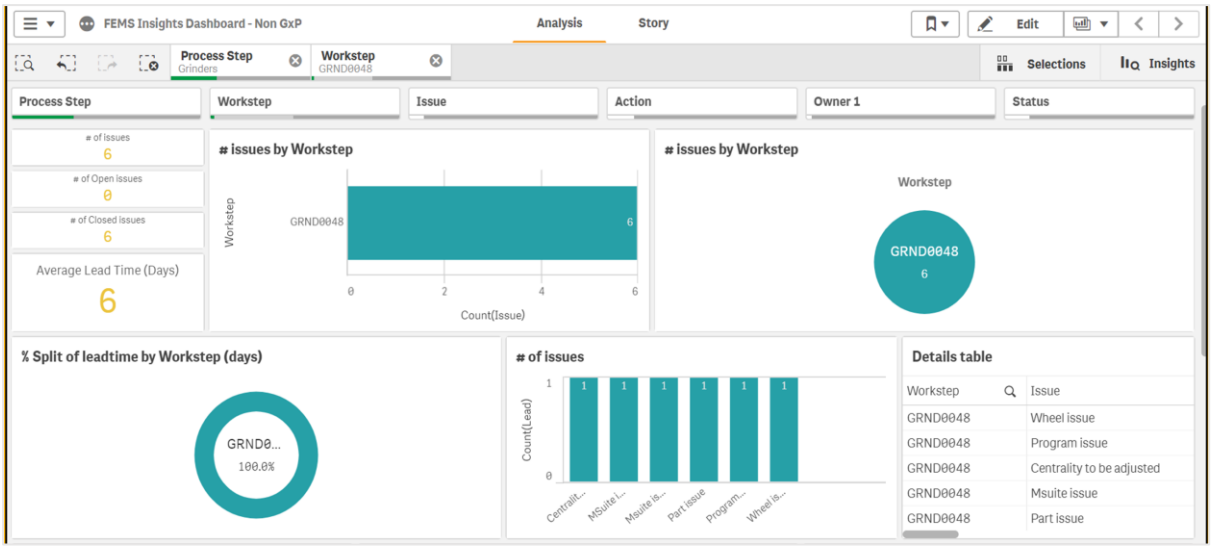


Figure 5.2-8 Issue Insight dashboard filtered to show GRND0048 data

5.3. Development of Design

The tool has been updated to include the suggestions from Step 5 of the methodology.

5.3.1. Demo feedback

During the demonstration of the proof of concept to staff, they indicated that they would be interested in using the tool on interactive screens. Following this feedback, the tool has been developed to be trialled using an interactive screen as well as an iPad on the Pulse Walk to log issues.

A request was made during the development of this tool to have a way for the operators and other staff working on the factory floor to have a means of sharing any ideas they had regarding improving processes on the factory floor. This is a Lean methodology that is discussed in Chapter 2.

An online google sheets document was set up, in the same style as the digitised Pulse Walk boards, as shown in Figure 5.3-1. This sheet allowed for staff to detail the location or work step their idea was from, along with any actions they felt should be taken and an owner. Provisionally these ideas are aimed to be discussed within two weeks before a further course of action is decided.

IDEA LOG FOR FEMS			*Ideas should be dealt with within 2 weeks					
Workstep *What area idea is related to*	Idea *Describe your idea*	Action *Follow up actions*	Owner 1 *Name an owner*	Due*	Status Open	Closed	Escalated	Notes
Pulse walk	Implement a tool to digitise issue logging	Standardise tool	Annie Duffy	10-Jun-19	27-May-19			

Figure 5.3-1 Idea logging page

Another request was made during the demo stage. The staff on the Pulse Walk mentioned that it would be beneficial to include the Qlik dashboard for OEE reason codes. These outline the reasons for machine downtime that are recorded by operators on the factory floor. Figure 5.3-2 shows an example of this dashboard. The FEMs Value Stream is selected, and the data can be filtered by day, week and month. Usually, this page is printed and brought along to the Pulse Walk by one of the attendees. Having it readily available via the developed tool will improve the accessibility of this data and minimise time wasted retrieving this information. It will also make it easier for everyone attending the Pulse Walk to see it, instead of having it on an A4 sheet.

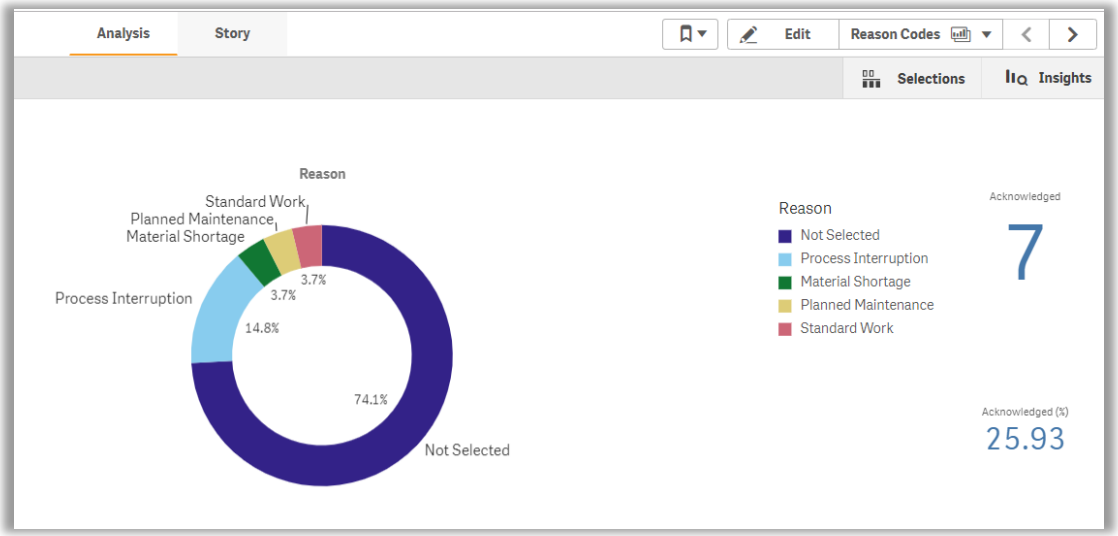


Figure 5.3-2 Qlik dashboard for OEE

6. Trial and Workshop

After the survey and demo, the proof of concept for the tool to digitise the Pulse Walk was finalised. The tool was trialled on the floor as part of the Pulse Walk to test its practical value.

6.1. Trial Implementation

The first trial consisted of setting the tool up for use on an existing screen beside the KPI board, the fifth step of the Pulse Walk. This was done by extending the screen of a laptop via an HDMI lead. The menu screen was shown on the page, with each data source accessible through the internet connection on the laptop. A wireless keyboard was used to enter issues on the digitised Pulse Walk board, which was connected via a Bluetooth USB dongle plugged into the laptop.

This was originally done for the fourth step of the Pulse Walk, the LCS board, which deals with the low-contact stress implants. This was chosen as it was the penultimate step of the Pulse Walk that could easily be relocated for the trial, and it meant that the staff involved were at the location for the final step, the KPI boards. This would not add much of a delay onto the regular running of the Pulse Walk as staff would not be required to walk to a different location off the path of the Pulse Walk for the trial to take place.

This location was again used for trialling the first stage of the Pulse Walk, the clean-room and shipping step. The trial step was changed because only a few issues were being dealt with on the LCS board at that time. The minimal amount of issues being recorded at the LCS step meant that the tool was not getting much use. Using the clean-room and shipping stage meant that it would not cause significant delays as the screen was located between the original area for the first and second step of the Pulse Walk, shown in Figure 6.1-1

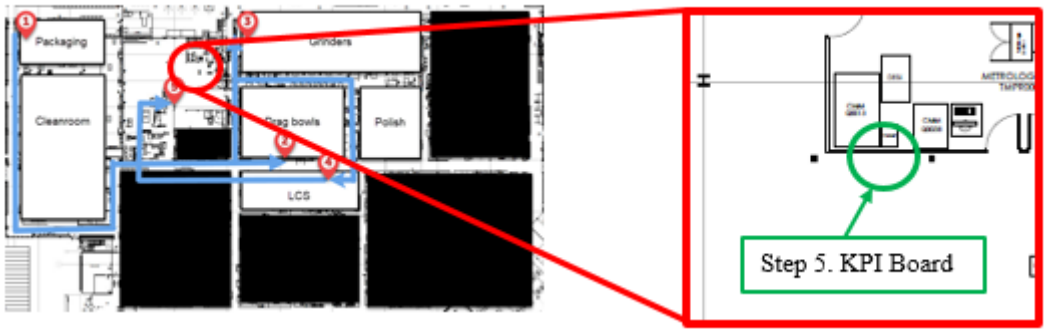


Figure 6.1-1 Location of screen used for first trials highlighted in green

The trial at these steps was acceptable; however, due to the nature of the steps chosen, there were only a few issues that needed to be logged using the digital Pulse Walk board. In order to 'stress test' the tool, it was decided to continue the trial at a busier step of the Pulse Walk, the third step, which is Grinders. The location for this trial is shown in Figure 6.1-2.

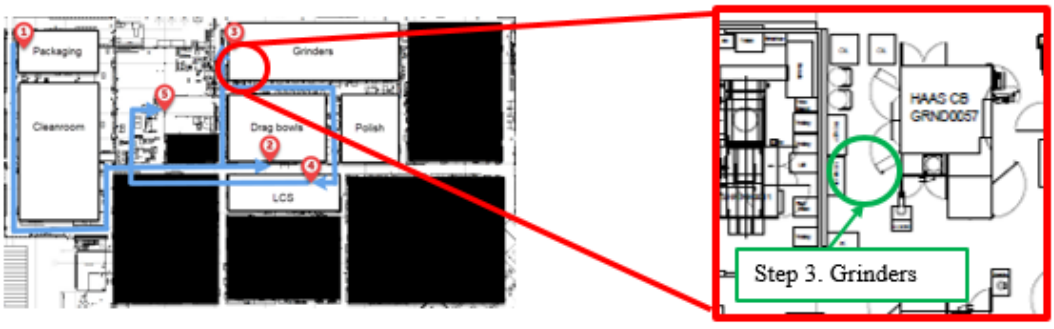


Figure 6.1-2 Location of portable screen for trial at Grinder step highlighted in green

A portable television screen was moved onto the factory floor in the area where the Pulse Walk meeting usually occurs for the grinders step to carry out this trial with an interactive screen. This was set up in the same way, extending the laptop screen and using a wireless keyboard to enter any new issues. The trial at this stage encountered many more issues to be logged in the DMIN tool, as expected. This provided ample opportunity to use the tool during the Pulse Walk, for both issue logging and accessing the various data sources provided.

The company issued iPad was also used to trial the DMIN tool at the Grinders step of the Pulse Walk, as it had become clear that the previous steps that the screen had been trialled on were not encountering sufficient issues to make it worthwhile. This trial commenced the following day after the completion of the screen trials. This was beneficial as staff were already familiar with the functionality of the DMIN tool by this point, making it easier to integrate it into the usual running of the Pulse Walk via the iPad. The iPad worked successfully, however some staff members experienced difficulty reading the smaller font sizes that were a result of using the smaller screen.

Furthermore, the iPad was also trialled on a full Pulse Walk, entering issues at each step and the KPI board. This was done to illustrate how the iPad can be involved throughout the Pulse Walk, providing issue logging boards for every step in addition to access to each data source at any point on the factory floor. A QR code was used during this trial, it was scanned at the beginning of the Pulse Walk to open the DMIN menu page. The iPad did not require to scan the QR code again during the trial as it already had the menu page open. This contained the issue logs for each step of the Pulse Walk, and data sources that encompassed the entire Value Stream, hence eliminating the need for further QR scanning.

The trials at the grinders step, and with the iPad on the floor were satisfactory as there was enough variation in problems to implement issue logging on the tool fully and provided many question points to discuss in the workshop. These questions dealt with practicalities of how the tool will be used; these are discussed in the next section.

6.2. Workshop

A workshop was used as a method to discuss the practical questions surrounding the implementation of the DMIN tool. This meeting allowed for a variety of staff to deliberate the tool and confer each aspect of how it will be used and what would be relevant to include. The workshop took place over 90 minutes, located onsite of the manufacturing facility. It was attended by an operator, a line facilitator, a Team Lead, a maintenance engineer and a quality engineer, alongside innovation engineers who are not involved with the Pulse Walk but who will support the uptake of this tool in the future. The workshop was separated into four sections:

- Hardware
- Data sources
- Issue logging
- Data analytics

Each section had talking points to be addressed, which were inspired by feedback and practical matters encountered during the trials. Time was allotted to the end of each section, allowing for any other feedback or ideas from the attendees. The meeting room walls could be written on in erasable white board marker, so any notes or points were written on the walls which were separated into the meeting headings.

6.3. Output from Workshop

The minutes of the review workshop were transcribed from the walls of the meeting room, they are discussed below.

6.3.1. Hardware

The tool was trialled on both screens and iPads. iPads were the original plan for the proof of concept, and the screens were a suggestion from staff after the demonstration before the trials. Both options have benefits, the iPads can be used to hold one-to-one conversations with issue owners and subject matter experts (SME) on the Pulse Walk. This is especially useful in areas of high noise levels, where it is difficult to hear conversations being held around the screen unless stood in close proximity to those speaking.

The screens are beneficial to use as they are large and can be seen by everyone on the Pulse Walk at each step. They can be used as a direct replacement of the whiteboards currently used on the Pulse Walk, using the same positioning and layout but will have access to the data sources in addition to issue logging.

During the workshop, the advantages of both options were discussed. It was decided that a screen should be used instead of the iPads. This is due to the iPads removing the group discussion element of the Pulse Walk. The iPads would also require specialised protective

casing if they are to be used on the factory floor, especially around the Grinders area due to oil and other contaminants that could damage the device. As a result, QR codes will not be necessary for the further development of the DMIN tool.

The plan is to use 50" interactive screens in place of the whiteboards at each step of the Pulse Walk. Ideally, the screens will be touch-capable and will be used with a pen or a virtual keyboard. As the screen will be large the keyboard should not span the entire width of the screen. Instead the keyboard should be centred on the bottom, it should also be movable so that it can be placed in a different area of the screen if necessary. This will be accessible to everyone with a card swipe action to log in. This will be used to identify who has edited entries in the changelogs.

An advantage of using the iPads was to support conversations in areas of high noise, action must be taken to tackle this noise distracting the Pulse Walk discussions. To remedy this, the Grinders and LCS boards are going to be combined and positioned in a new location, in an area with less noise. Figure 6.3-1 shows the original route for the Pulse Walk, covering the five steps. Figure 6.3-2 shows the new route for the Pulse Walk, Steps 3 and 4 have been joined and moved to the right of the map.

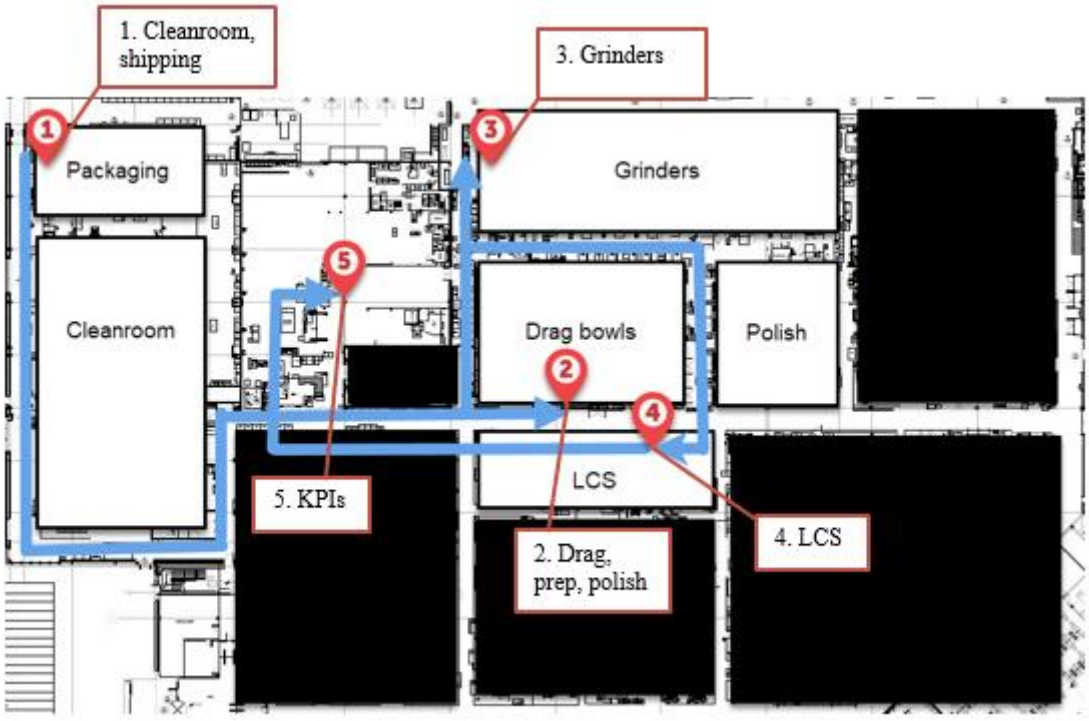


Figure 6.3-1 Original path of Pulse Walk

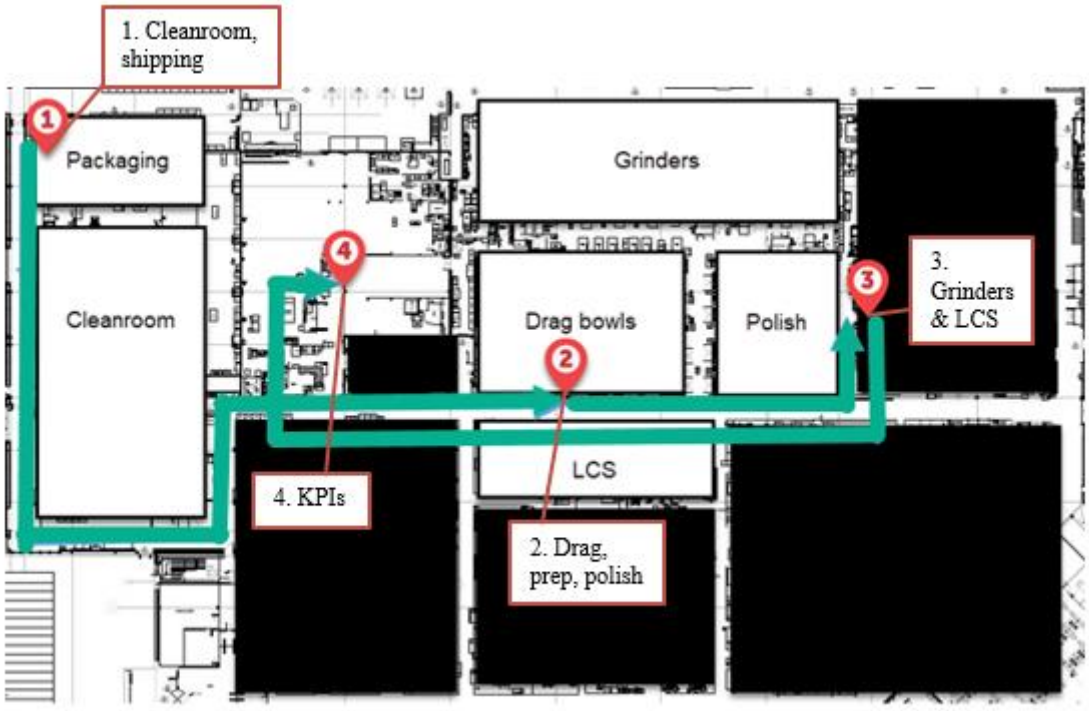


Figure 6.3-2 Proposed path for future Pulse Walk

6.3.2. Data Sources

The data that is currently included in the tool is OSI Pi, showing the OEE of machines through Pi Vision dashboard, Qlik scrap dashboard and a Qlik dashboard for OEE. The latter of which was suggested during the trials and daily updates from it are necessary during the Pulse Walks.

The survey that was sent out during the development of the project gave people an option to suggest any other data sources that would be worthwhile including as part of the DMIN tool. The data sources offered as options in this survey, along with those suggested from the responses were discussed. This was to determine which, if any, would be helpful to have as part of the DMIN tool.

Maximo, which stores maintenance work orders, was the third most voted option to be included in the DMIN tool from the survey. This data source is to be included in the DMIN tool, as part of the issue logging page. An extra column will be added to hold the work order number, usually in a '#_____' format, containing six digits after the hash. This will contain the URL of the Maximo ticket, and clicking on it will open it. A table with open Maximo work orders will be included as a standalone data source in the DMIN tool.

Other options from the survey include Safety and Curve, and it was agreed at the workshop that these would be included in the fifth screen, beside the KPI boards. The information included from these sources at this step would encompass the length of the Pulse Walk, not just one step. This location will also be used to show another suggestion from the trial, excess WIP locations, which is where the excess batches are stored on the floor.

Other suggestions from the survey to be included as a visual representation on each board:

- Reprocessing, which details any aged work orders that were put on hold for different reasons being reintroduced into the process,
- Material review reports (MRRs) in process, which describe any batches sent back for rework,
- Scrap from reprocessing.

Energy data was a suggestion from the survey to be included in the tool. Although this will not benefit the Pulse Walk directly, all attendees of the workshop agreed that it would be worthwhile including- in the hopes of drawing attention to the energy usage on the floor. The energy use will be shown as a tracker in the corner of each board, a week on week graph to monitor and encourage good behaviour – such as shutting down machines when idle. This will benefit the company in the long term as minimising energy use where possible will save costs.

Temperature charts for associates was suggested in the survey to be included in the DMIN tool. This option was discussed at the workshop, however, it was decided that this information could cause conflicts with General Data Protection Regulation (GDPR) as it contained personal data for each associate and should not be made available for other staff to see. For this reason, this data sources will be omitted from the DMIN tool.

A suggestion was made during the workshop by an operator in attendance to include Day by the Hour (DBTH) targets. After some discussion, it was agreed that these are critical to production and very beneficial to include on each pulse board. This information is stored in an Excel spreadsheet and can be pulled to Qlik for visualisation. It was requested that this information can be printed for distribution among operators working on the factory floor. Mock-ups of these screens are shown in Figure 8.5-1, Figure 8.5-2 and Figure 8.5-3 in Chapter 8.5 during discussions for future work.

6.3.3. Issue Logging

The issue logging page was reviewed during the workshop. All those attending agreed that the current layout, which mimics the original Pulse Walk whiteboard works well so it will be kept as it is, with a few additions that are explained below.

The topic of adding updates to existing entries was brought up. There has been several examples from the trials when an issue was recorded, and updates for it led to another action being logged. To avoid overwriting the original entry in the issue logging board, a suggestion was made to have an 'Add Update' option to the entries, which will attach the new issue or action below the initial entry. This will keep all related entries together in chronological order without overwriting any data so that it can all be recorded and used in data analysis.

Another feature that will be added to the tool is email notification. When an issue is entered, it will send an automated email to the owner. This will ensure that everyone will be aware of any issues they are responsible for dealing with, even if they could not attend the Pulse Walk.

Ideally, when an issue is logged, it will have an option to create a Maximo or Safety ticket from the information entered. This will avoid the need to enter the same information twice in two locations.

As mentioned in the section above, Maximo will be included in the tool. A column will be added that will contain the URL to the Maximo ticket of the issue. Another column will be added to the issue logging board, which will describe which product family each issue is in relation to. This will be used in the data analysis, discussed in the next section. The column for Owner 2 will be left as-is for the meantime, but ideally, each issue should only have one owner.

As each issue is meant to be dealt with within 24 hours, colour coding was suggested as a way to emphasise the issues that are 'overdue'. A traffic light system will be introduced for each row highlighting the older problems.

At present, there is a board in use at the grinders step on the factory floor, which uses red and green cards beside a list of machines to show which are running and which are not. This allows people to scan and see which machines need attention quickly. This will be used in the issue logging board; a column will be added to the sheet for machine status. This will be colour coded red for off and green for on. This information can be pulled from the machine OEE information on OSI Pi.

To speed up the Pulse Walk issues will be closed off by checking a box in the closed column, this will record the date and time the issue was completed at instead of having to type it in. This will also help avoid errors in entering the dates, which will keep the data analysis of lead times more accurate.

The checkboxes at the top of the boards will be recorded and presented to the Value Stream Manager as a weekly report, along with attendance at each step – possibly through card scanning although this may have time delays. Other methods of taking attendance will be investigated, potentially using a checklist manually or digitally could be used.

Figure 6.3-3 shows an example of what the issue logging table would look like with these suggestions implemented. There is a column added for machine status, which is colour coded. A column has also been added to record product family of each machine. The closed column has been changed to show checkboxes, and there is a column added for Maximo ticket numbers. The ticket numbers shown are just example codes, highlighted in blue to show that they are hyperlinks that can be clicked to open to the selected Maximo ticket.

Workstep	Machine Status	Product Family	Issue	Action	Owner 1	Owner 2	Due	Status		Notes	Maximo	Lead Time	Days Overdue
								Open	closed	Escalated			
GRND0096	Running	Sigma CR	Excessive noise from filtration	Investigate	Maintenance	Engineering	26-Jun-19	5-Jun-19	☑		Part ordered	#7777777	0	0
GRND0056	Running	LCS	Chiller unit issue	Fix	Maintenance		6-Jun-19	4-Jun-19	☑		contractor on site	#7676767	0	0
GRND0047	Running	Sigma CR	Program issue	Adjust	Engineering		7-Jun-19	7-Jun-19	☑		Size 5 program turned off		0	0
GRND0059	Running	Sigma CR	Parts uneven	Fix	Tool room		7-Jun-19	7-Jun-19	☑		Size 5 Sigma CR Arbour parts pulled out		0	0
GRND0054	Running	LCS	Wheel issue	Monitor	Maintenance	Engineering		19-Jun-19	☐		imbalance to wheels/grinding wheels	#7575757	0	0
GRND0078	Down	Sigma PS	Tool Break	Adjust	Engineering		2-Jul-19	7-Jun-19	☐		6mm ballnose tool/monitor when size 6 is back		0	0
GRND0075	Running	Attune PS	Program issue	Fix	Engineering	Maintenance	25-Jun-19	20-Jun-19	☑		program not loading		0	0
GRND0097	Down	Sigma CR	Spindle issue	Change	Maintenance		25-Jun-19	21-Jun-19	☐		change spindle	#7474747	0	0
GRND0078	Running	Sigma PS	Belt issue	Fix	Maintenance	Engineering	25-Jun-19	24-Jun-19	☑			#7373737	0	0

Figure 6.3-3 Example of the issue logging table including workshop feedback

Throughout the development of this tool, the KPI boards were kept as free text entries as the issues logged here are so varying it would be challenging to standardise them. It was agreed at the workshop that they would be kept as free text, columns will be added for owner, described as department instead of staff names. A column for work step or area will likewise be added to assist in tracking and analysis or issues. Email updates will also be sent out to owners at this step. Figure 6.3-4 shows an example of this table with the suggested updates, the added 'Work step / Area' column and owners listed as a department.

Action Log							
Date Raised	Workstep / Area	Action	Owner	Due Date	Status	Escalated	Notes
18-Oct-18	Grinders	Top 5 Priority guages - meshing kiel	Operations	19-Jun-19	Ongoing		
12-Feb-19	Drag, prep, polish	Plan to be developed to reduce WIP levels at hashing	VS Mananger	Ongoing	Closed		
31-May-19	TUMB0006	PM Ceramic bowls	QA	13-Jun-19	Open		
31-May-19	SHAD0003	Lock out	Maintenance	6-Jun-19	Open		

Figure 6.3-4 Example of the KPI board with suggested changes

An idea logging page is already included as part of the tool. The feedback from the workshop was positive, so this will be included in the future. It will be set up similarly to the issue logging page, where the owner of each idea is the person who logged it- this name will be available to managers but not shown on the screen. An email will be sent out when a new issue is logged. A key point expressed by attendees of the Pulse Walk is that the feedback from these ideas must be shared with all three shifts, the information can be available on the digitised board. It is important to keep this section away from metrics and to allow the organic development of ideas from associates on the factory floor. Project meetings with managers and Team Leads will discuss the Pulse Walk attendance and any ideas suggested from this part of the tool.

An additional suggestion was made at the workshop, to include a communication sheet as part of the tool. This will be on each Pulse Walk board, available to everyone. This will be used to share any handover information to the next shift coming on.

It is vital to ensure that the tool does not become overloaded with information. Although each suggestion may be beneficial to have, too many data sources could cause confusion for the users. Bearing this in mind, the tool will be developed to include these suggestions but it will be trialled and tested before being put to use on a Pulse Walk. This will point out if there is any excess data sources cluttering it that can be removed.

6.3.4. Data Analytics

The Qlik dashboard for issue insights was reviewed as part of the workshop. Each graph was discussed and decided whether it was relevant. Figure 6.3-5 below shows the first row of these charts. The number of issues and lead time widgets on the left of the screen are to continue to be included, along with the bar chart titled “# issues by Work step”. This graph describes the

amount of issues at each work step. The pie chart which showed the number of issues at each work step will be removed as it was deemed unnecessary beside the corresponding bar chart mentioned previously. This chart will be replaced by the donut chart on the right which illustrates the percentage split of lead time per work step. This chart will replace the work steps with product families. The product families will be added as a column to the issue log table, as discussed in Chapter 6.3.3. These charts are shown in Figure 6.3-5.



Figure 6.3-5 First three charts on the updated Issue Insight dashboard

The chart titled "# of issues" which shows the amount of each issue will also be included. This is shown in Figure 6.3-6.

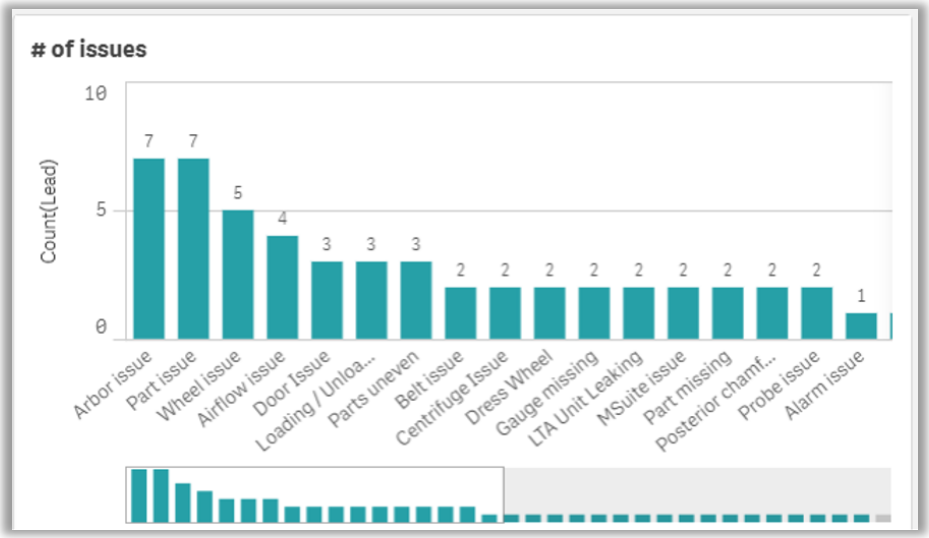


Figure 6.3-6 Number of issues chart

The bar chart “Total lead time by Work step” will be removed as it was deemed irrelevant during the workshop. The chart “Total Lead time by Owners” will be included, however the owner’s names will be replaced by the corresponding department instead to avoid any GDPR issues. This will also be the case for the graph “Count of Issue by Owner with Lead time” which will continue to be included. The list of departments is as follows:

- Calibration
- QA
- Processing
- Maintenance
- Operations
- Tool Room
- IT
- Planning

These graphs are shown in Figure 6.3-7 and Figure 6.3-8.

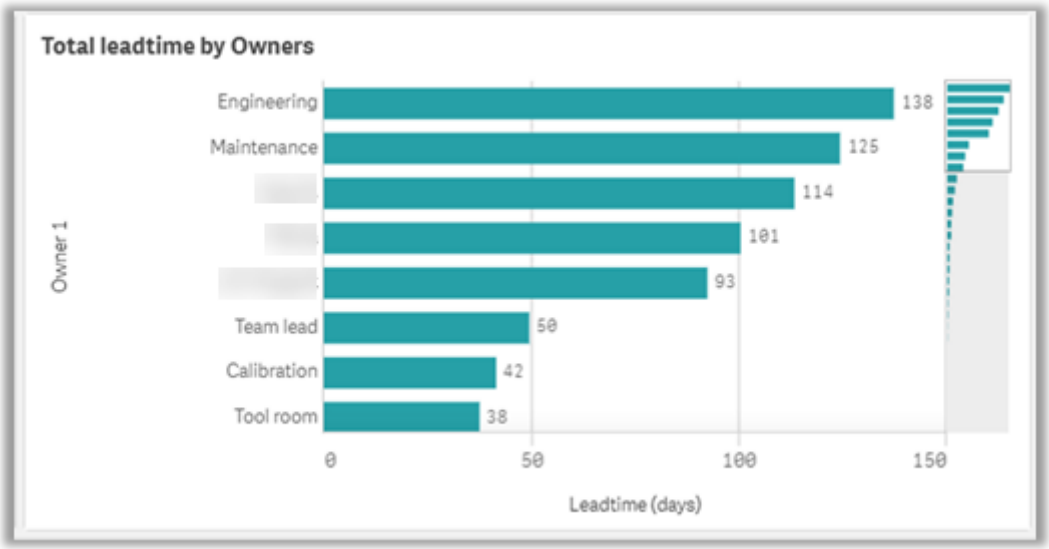


Figure 6.3-7 Chart showing Total Lead time by Owners

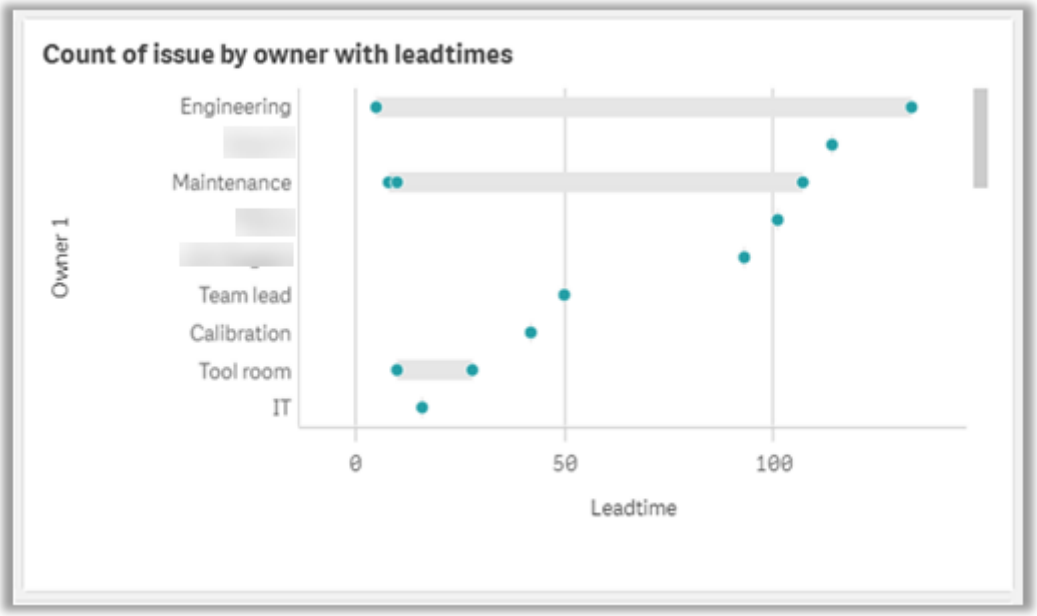


Figure 6.3-8 Count of Issue by Owner with Lead time

These graphs will form the next section of the dashboard, shown in Figure 6.3-9.

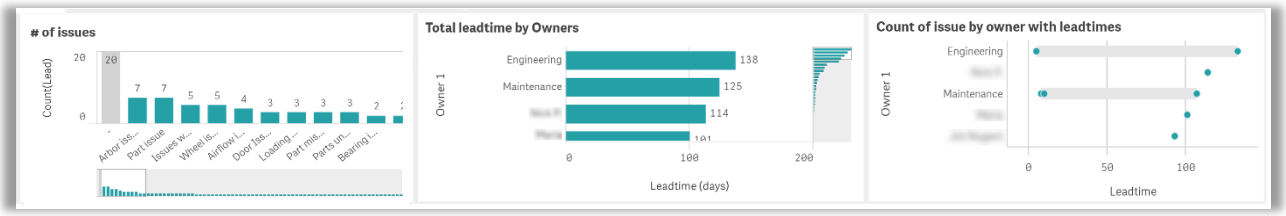
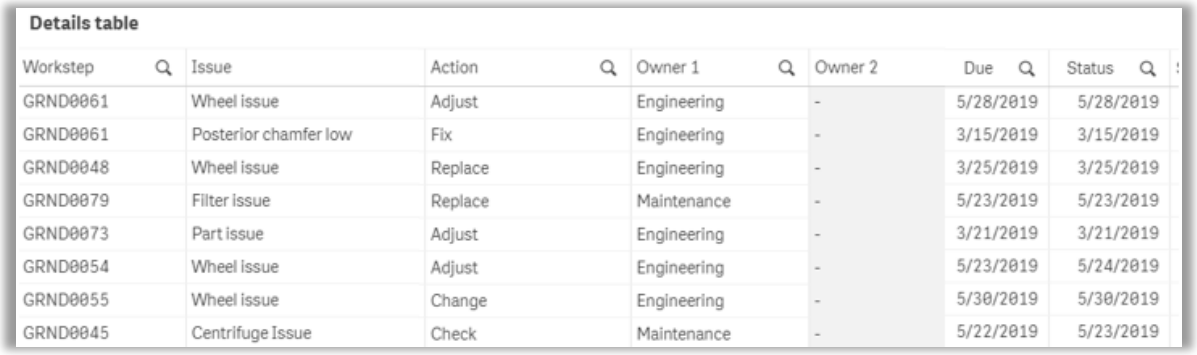


Figure 6.3-9 Second three charts on the updated Issue Insight dashboard

The details table will be moved to the bottom of the dashboard to avoid clutter. This will be the width of the screen and will show the columns from the issue logging table, including the 'Notes' column to provide details to any filtered problems as discussed in Chapter 6.3.3. This table is shown below in Figure 6.3-10.



Details table

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status
GRND0061	Wheel issue	Adjust	Engineering	-	5/28/2019	5/28/2019
GRND0061	Posterior chamfer low	Fix	Engineering	-	3/15/2019	3/15/2019
GRND0048	Wheel issue	Replace	Engineering	-	3/25/2019	3/25/2019
GRND0079	Filter issue	Replace	Maintenance	-	5/23/2019	5/23/2019
GRND0073	Part issue	Adjust	Engineering	-	3/21/2019	3/21/2019
GRND0054	Wheel issue	Adjust	Engineering	-	5/23/2019	5/24/2019
GRND0055	Wheel issue	Change	Engineering	-	5/30/2019	5/30/2019
GRND0045	Centrifuge Issue	Check	Maintenance	-	5/22/2019	5/23/2019

Figure 6.3-10 Details table on the updated issue insight dashboard

There will be extra options added to the headings across the top of the dashboard to make it easier to filter the data in all of the charts included. An option for searching by date and product family will be included.

6.4. Discussion

This workshop has been used to get feedback from the staff about what they would like to see included in the tool. The ideas deliberated during the meeting are all recorded above; Table 6.4-1 shows a summary of the suggested data sources from the survey. The tool outlined from this would be the version used in an ideal world; however, this might not be possible right away. Discussions will be had to decide what the future of the tool will be, using the information provided here as a guide of what the staff on the Pulse Walk would like and what would be beneficial to include.

One of the main hurdles that digitising the Pulse Walk should overcome is the time taken to complete the Pulse Walk. A Pulse Walk currently takes 30-45 minutes, when it should preferably be around 20. Screen loading time must be minimal to avoid unnecessary delays.

Data Source	Included	Reason
OSI Pi OEE dashboard	Yes	Top voted data source from survey, contains useful OEE data for machines
Qlik Scrap dashboard	Yes	Second voted data sources from survey, Daily updates are monitored during the Pulse Walk
Qlik OEE dashboard	Yes	Daily updates are necessary during the Pulse Walks
Maximo	Yes	Used to show maintenance work orders
Safety	Yes, 5th board	Details Good Saves for the whole Value Stream, not relevant for daily Pulse Walks
Curve	Yes, 5th board	KPIs for the whole Value Stream, not relevant for daily Pulse Walks
Temperature Charts	No	Excluded due to GDPR conflict
Energy data	Yes	Will draw attention to the energy usage on the floor
Reprocessing	Yes	Details any aged work orders that are on hold
Scrap from Reprocessing	Yes	Indicates any scrap as a result of reprocessing
Excess WIP locations	Yes, 5th board	Not relevant for daily Pulse Walks
MRRs in process	Yes	Describes any batches sent back for rework
Day by the Hour target	Yes	Critical to production

Table 6.4-1 Summary of survey suggestions

7. Use Cases

7.1. Improving Information Access and Speeding up the Pulse Walk

The primary use case for this tool is to improve the Pulse Walk. This will include improving the speed of the process and improving access to information during the meetings. By providing a digitised platform to show each data source on, time can be saved accessing all of the relevant data.

By implementing the DMIN tool that has been suggested, it will improve the standardisation of logging issues. This is done through the use of the issue codes outlined for each step. This will streamline the process of logging and subsequently closing out issues.

7.2. Highlighting Problematic Areas

The utilisation of the DMIN tool will introduce a historical log of issues, stored in the online database of the digitised Pulse Walk board. Performing analyses on this data, such as has been done in the 'Qlik Issue Insight Dashboard' that is provided in the DMIN tool, allows for investigation into any recurring areas or work steps.

Figure 7.2-1 shows the dashboard, we can see from the highlighted graph that one of the most recurring issues for the chosen step of Grinders is 'Parts issue'. Furthermore, as this part has been highlighted, the Qlik dashboard will filter the remaining charts to show each one in relation to this selected issue type. We can see that this issue affects a range of work steps with the most prominent being GRND0075 and GRND0078.

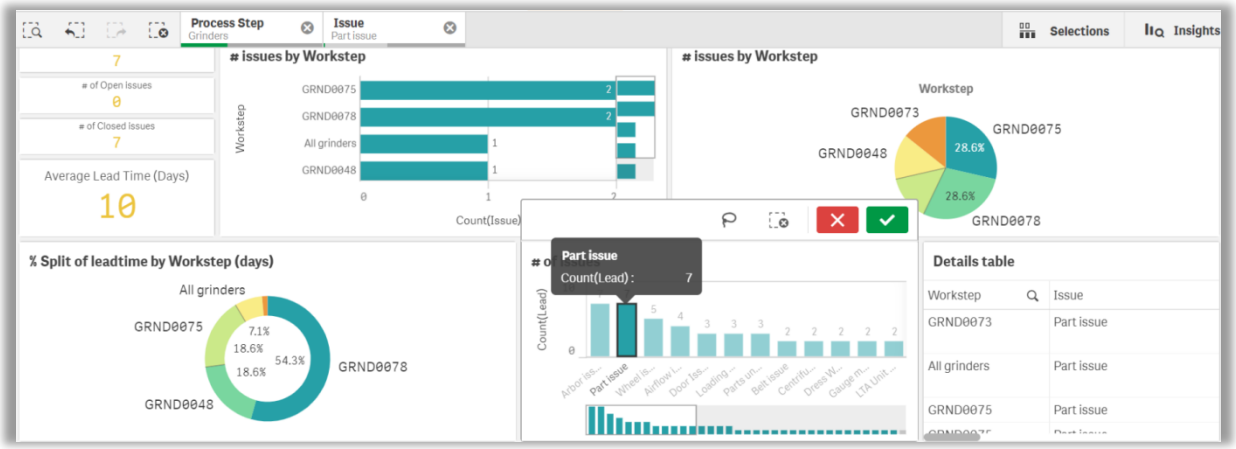


Figure 7.2-1 Issue insight dashboard

When we search for 'part issues' in the Issue logging board, we can see the range of problems that are encountered under this name. Shown in Figure 7.2-2 we can see that with the exception of the first issue at 'All grinders' and the light problem at GRND0048, the majority of the issues are in relation to a 6mm ball nose part breaking on GRND0073, GRND0078 and at GRND0075 on two occasions in the month of May.

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes
						Open	Closed	Escalated	
All grinders	Part issue	Fix	Maintenance		7-Mar-19	6-Mar-19	11-Mar-19		Blue allen keys are all rounded and no longer usable
GRND0073	Part issue	Adjust	Engineering		21-Mar-19	20-Mar-19	21-Mar-19		6mm ball nose breaking after only 1hr1/2
GRND0048	Part issue	Monitor	Engineering	Maintenance	7-May-19	2-May-19	15-May-19		Lights on stop not working
GRND0078	Part issue	Monitor	Engineering		7-May-19	23-Apr-19	16-May-19		6mm ball nose
GRND0075	Part issue	Replace	Engineering		14-May-19	9-May-19	16-May-19		6mm ball nose Att PS s2 6 LT + RT
GRND0075	Part issue	Recover	Engineering		28-May-19	23-May-19	29-May-19		6mm ball nose part breaking

Figure 7.2-2 Filtered issues by 'parts issue'

When investigating GRND0078 as it is shown to be one of the tools with the most issues on the Grinders step, the problems with the 6mm ball nose part is further emphasised. Figure 7.2-3 shows the issues encountered at GRND0078, which range from cracked shutter doors to belt issues but again the most prominent is issues with the 6mm ball nose part. We can see that it is logged as a 'part issue' on the 23rd of April. This issue is dealt with after 23 days and closed on the 16th of May, which is a very prolonged lead time. The problem reoccurs and is logged as 'Tool break' on the 23rd of May, indicating that the problem has escalated or was not dealt with

properly. This tool breaks again on the 7th of June, meaning the 6mm ball nose part caused issues thrice over 3 months, including breaking.

By making this data clear and available, precautions can be taken to prevent these parts from breaking as frequently. Consideration can be given to keeping spares on-site to deal with recurring breakages on certain parts. Alternatively, if necessary in the future, other vendors or materials could be investigated for use in the place of the currently used ones as they might offer a better life span before failing. By improving the life span of this part, efficiency can be improved as the production will not be halted in the event of the part being damaged or broken. This will save on costs of reprocessing damaged parts, and minimise any backlogs of orders while the part is repaired or replaced.

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes
						Open	Closed	Escalated	
GRND0078	Run all size	Monitor	Engineering	Planning	21-Mar-19	20-Mar-19	21-Mar-19		Run all 6L only
GRND0078	Door Issue	Fix	Maintenance		16-May-19	14-May-19	17-May-19		shutter door cracked
GRND0078	Part issue	Monitor	Engineering		7-May-19	23-Apr-19	16-May-19		6mm ball nose
GRND0078	Tool Break	Monitor	Engineering		29-May-19	23-May-19	6-Jun-19		broke 3 tools on 6 parts, 6mm ballnose on Attune PS
GRND0078	Tool Break	Adjust	Engineering		2-Jul-19	7-Jun-19			6mm ballnose tool / monitor when size 6 is back
GRND0078	Belt issue	Fix	Maintenance	Engineering	25-Jun-19	24-Jun-19	26-Jun-19		

Figure 7.2-3 Issues filtered by GRND0078

7.3. Energy Efficiency

Using data capture and knowledge management to highlight problematic areas allows for these problems to be addressed. Having the historical database can assist with managers understanding of where inefficiencies are occurring, being able to articulate where energy is being consumed in excess will make it easier to find areas to focus on reducing energy use. Using the example discussed above, with the repeated issues surrounding the 6mm ball nose tool- improving this tool either through maintenance, change of material or change of vendor can reduce the issues that are caused by it. Furthermore, the problems being caused by this tool could be unrelated to material or type used, but instead mishandling at the responsibility of the operators. The reasons for this tool repeatedly failing is unknown at this point and requires further investigation to understand it fully. Providing the database prompts this root cause analysis to happen.

By investigating the issues in the database, managers can use root cause analysis to outline ways to prevent them from reoccurring in the future. This is aligned with the Lean mentality of 'Jidoka' and 'Andon', to highlight an issue and improve the production line by solving the problem. By preventing reoccurring issues with machines or tools from continuously happening, there will be fewer problems encountered on the production line. By solving the problems that require parts to be reworked due to defects, or parts to be scrapped, it is reducing the work needed to amend the problems in the first place. Avoiding this work will minimise the energy wasted by trying to fix abnormalities in parts caused by defective tools or machines.

As the DMIN tool has not been officially put into use on the factory floor yet, there is no way to measure the success rate of this use case accurately. The medical device manufacturing company is striving to put in place energy monitoring systems to gain an understanding of energy use. They are aiming to achieve a vision for energy use for each building and each Value Stream. There are various energy streams involved in this factory, such as electricity supply, compressed air, gas, heating, and cooling water. These energy sources will all have to be metered for the building, and for each Value Stream of production to gain an idea of energy use. The measurement that will be used to determine the energy used in manufacturing is kilo-watt hour (kWh) per part. This will indicate the number of parts produced in one kWh and the average energy used to produce one part. If tools and machines that regularly cause issues are removed, repaired or replaced, this should minimise the time downtime, thus reducing the energy per part.

To get an understanding of the improvement delivered by the DMIN tool, energy will have to be monitored before introducing it, for the first period of it being in use and then when it has been fully immersed into the production process. The time slots for these stages would preferably be as long as possible to gain a full picture of average energy use. 3-6 months would be ideal for each stage, although it is understandable that this length of time may not be possible due to factory constraints or pressure to use the tool instead of waiting to measure processes without it. Comparing the energy used in each stage will provide insight into the benefits provided by the DMIN tool, and verify that there is less energy being used.

This aspect of the DMIN tool is essential as industries move to eradicate excess energy use to keep costs low. Although this use case is theoretical, the factory is already beginning to set up metering of the numerous energy sources in a bid to draw attention to energy use and reduce it across all aspects of production.

7.4. Investigating Overall Equipment Efficiency

The DMIN tool has proved to be useful in identifying the ripple effect of issues on the factory floor, and how these can impact OEE. For example, if a member of staff is using the DMIN tool to access the Pi vision dashboard for the local site they can access the overall Value Stream OEE, as well as each asset that is connected to OSI Pi historian. Currently, not every asset from the Value Stream is connected to OSI Pi to post its status and OEE. All Grinders from the third step in the Value Stream are connected, making this a reasonable example to use for the DMIN tool.

The data shown in this dashboard is updated every five minutes, so it is an accurate representation of the state of each machine. If the machine status is shown as ‘Idle’, it indicates that the machine is not in use, which is normal as some machines can only produce a specific size of parts which is not always required to run consistently. If the status of the machine is shown as ‘Paused’, ‘Unknown’, or ‘Alarm’, this could be cause for concern as there could be an issue with the machine, tool or part. The ‘Feed Hold’ or ‘Paused’ state is caused by a pause in the current cycle for the parts being produced and is different from being ‘Idle’. The ‘Unknown’ state is typically used when a machine is turned off or disconnected, as visibility is lost on what the machine is doing. Events are generated for each state other than running, operators can report on each of these states using a list of reason codes which is recorded in OSI Pi.

To check if there is anything out of the ordinary, the user can then return to the tool menu page to access the Issue Logging board, and search for the asset in question. This will return any issues associated with the machine. This can be used to see if there is an open issue being dealt with for that machine. If not further investigation may be required.

If the machine is in any state other than running, it’s considered not available. Downtime is counted when a machine is doing anything other than running parts. Matching the issue log to machine status can help indicate if a machine that is not available is due to scheduled downtime or an issue with parts, machines or tools.

Furthermore, if there is a lower than normal OEE level for the Value Stream, it can be investigated through the Issue Logging board. Occasionally there are setbacks that include machine maintenance to be carried out or putting parts on hold for manufacturing. Using the

Issue Logging board to find and investigate such problems can aid in organising the manufacture of other parts in the meantime.

7.4.1. Example at GRND0048

Using GRND0048 as an example as it is one of the machines with the most issues, we can investigate the machine around certain times to see if there is any link between issues logged and the recorded OEE. In Figure 7.4-1 below, we can see that for the previous day – Monday – the OEE is very low at 46% operational. The graph on the bottom of the figure shows the OEE for the Tuesday morning shift. We can see that there is a large section of the graph that is red to highlight the 'Alarm' state. The grey area indicates the machine is idle, and the purple is for unknown.



Figure 7.4-1 OEE for GRND0048 for Tuesday 19th of March 2019

As part of OSI Pi, operators have the capability to log a 'reason' for machine downtime. However, this is not always carried out to the required standard. We can see in Figure 7.4-2 below the unacknowledged downtime events for GRND0048.



Figure 7.4-2 Unacknowledged downtime for GRND0048 18th-19th March 2019

This low OEE continues into the next day. Figure 7.4-3 shows how the OEE has plummeted as the machine is sitting idle since the Monday evening shift. In the same manner as before, the OEE downtime has not been officially acknowledged using the reason codes provided in OSI Pi, seen in Figure 7.4-4.



Figure 7.4-3 OEE for GRND0048 Wednesday 20th March 2019



Figure 7.4-4 Unacknowledged downtime for GRD0048 19th-21st March 2019

As there is no explanation available for the lengthy downtime this machine experienced, sitting idling on the factory floor, we can investigate further. In order to find a reason for these wavering levels of OEE, we can use the DMIN tool. We can filter the issue logging dashboard to show any problems encountered for this machine, seen in Figure 7.4-5. Around the time of these low levels of OEE, there is an 'MSuite issue' logged for this machine. MSuite is a type of software which is implemented on the Grinder machines, it is used to run the programs for the manufacture of parts. If this is where the issue is, then it could have a tremendous impact on the running of the machine. We can see from Figure 7.4-5 that there have been three issues with MSuite for this machine, with the last recorded one noting that the software has failed and there is no communication.

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes
						Open	Closed	Escalated	
GRND0048	Msuite issue	Monitor	Engineering	Maintenance	7-Mar-19	2-Mar-19	8-Mar-19		
GRND0048	MSuite issue	Investigate	Engineering	Maintenance	20-Mar-19	19-Mar-19	20-Mar-19		program reboot error
GRND0048	Wheel issue	Replace	Engineering		25-Mar-19	25-Mar-19	25-Mar-19		wheel change
GRND0048	Centrality to be adjusted	Adjust	Engineering		21-May-19	20-May-19	22-May-19		
GRND0048	MSuite issue	Replace	Engineering	Maintenance	7-May-19	2-May-19	16-May-19		Msuite fails, no communication
GRND0048	Part issue	Monitor	Engineering	Maintenance	7-May-19	2-May-19	15-May-19		Lights on stop not working

Figure 7.4-5 Issues logged for GRND0048

Figure 7.4-6 shows the OEE around the time of the software failure between the 9th and 10th of May 2019. We can see that the OEE for the previous few days has been reduced, the table

showing the OEE levels indicates the OEE for Wednesday and Thursday's day shift remained between 50 and 70%, with an improvement on Thursday night, reaching 89%. In the graph at the bottom of Figure 7.4-6, we can see that the machine is mostly on, with some idle times dotted throughout. It is normal for machines to have some idle time between processing batches as they are not required 24 hours a day. The orange segments in this graph indicate the machine is in 'Feed hold' state. This could be a result of the issue with the MSuite software, as we can see from the issue logging board that this problem was not closed until the 16th of May. Using this as a basis, we can determine that the issue was being repaired during the aforementioned period. This repair could have had a negative impact on the OEE for this grinder.

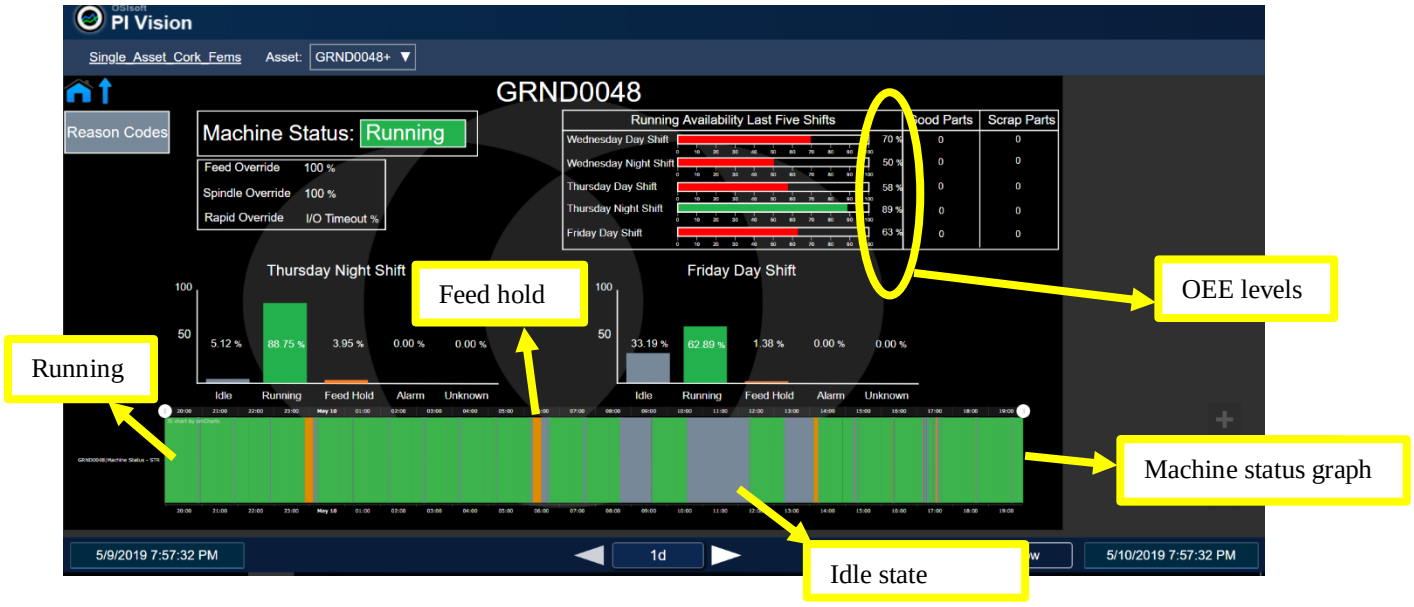


Figure 7.4-6 OEE for GRND0048 on Friday 10th May 2019

Figure 7.4-7 shows the OEE for the proceeding days, Saturday 11th and Sunday the 12th of May. Although the OEE shown here is poor, with the reading for Saturday day shift at only 5%, it is important to consider the days of the week these readings are from. As it is a weekend, the factory is not running at full capacity. We can see that the machine is mostly standing idle during this time as it is not in use.

Another take away from Figure 7.4-7 is how often the machine is idle. This is understandable if it is waiting between batches to process, however, if this machine is in an idle state for large amounts of time, it could be a drain on electricity. Monitoring will have to take place to decide if it costs less energy to switch the machine on than it does to keep it standing idle. If this is the

case managers, Team Leads and supervisors should work to outline a production plan. This will align with the Lean methods mentioned in Chapter 2. Using a production plan will allow them to forecast which machine will be on to process specific batches. If they know a machine will not be required for use for a day or several hours, it can be switched off to save energy.



Figure 7.4-7 OEE for GRND0048 11th - 12th of May 2019

7.4.2. Example at GRND0059

Investigating GRND0059 as there are many issues logged at this machine, we can see a similar trend in the OEE being lower than desired. Around the 15th of March 2019, there is a drop in OEE towards the end of the week. Figure 7.4-8 shows the Friday day shift. The OEE table shows the levels dropping to 28% on Thursday evening. The graph along the bottom shows the machine was moving between running and idle states with brief periods in feed hold. Moving between running and being idle is normal if the machine is on throughout the day, as batches will be loaded into it and removed continuously.

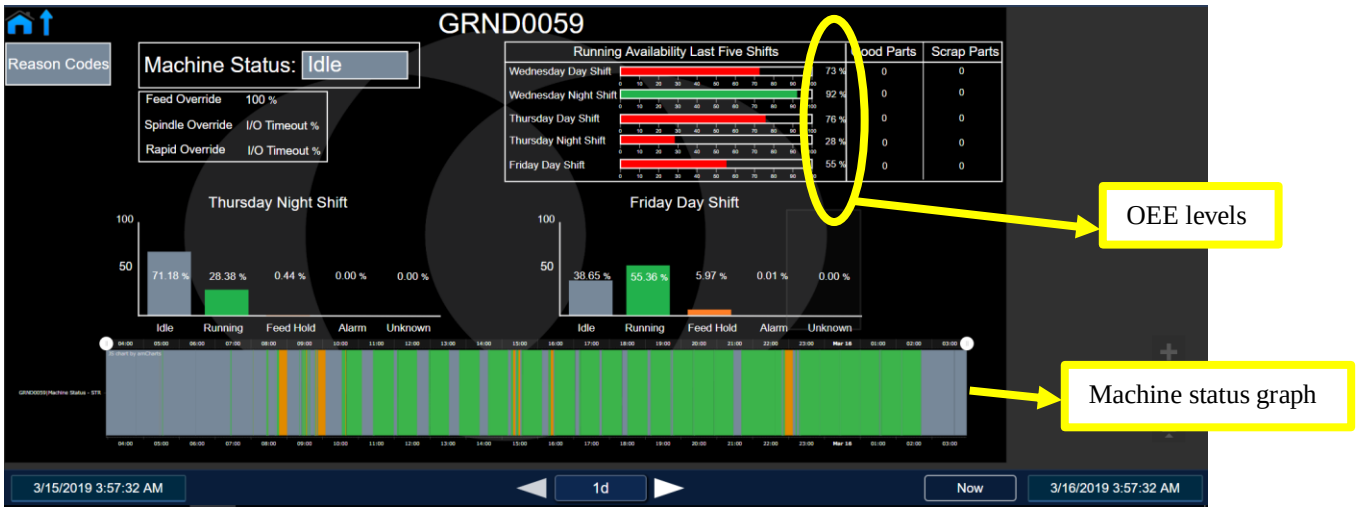


Figure 7.4-8 OEE for GRND0059 Friday Day shift 15th March 2019

Moving on to the night shift for Friday shown in Figure 7.4-9, we can see that the OEE is still very low charting at 55% and 58% for the day and night shift, respectively. Although the graph at the bottom indicates the machine was running for the majority of the evening, there is a brief feed hold state between 10 and 11 pm. There is a length of time when the machine is idling during the night between 2-7 am. Although the factory runs during the night, it could be doing so with limited use of machines which would explain why this machine was not in use between these times.

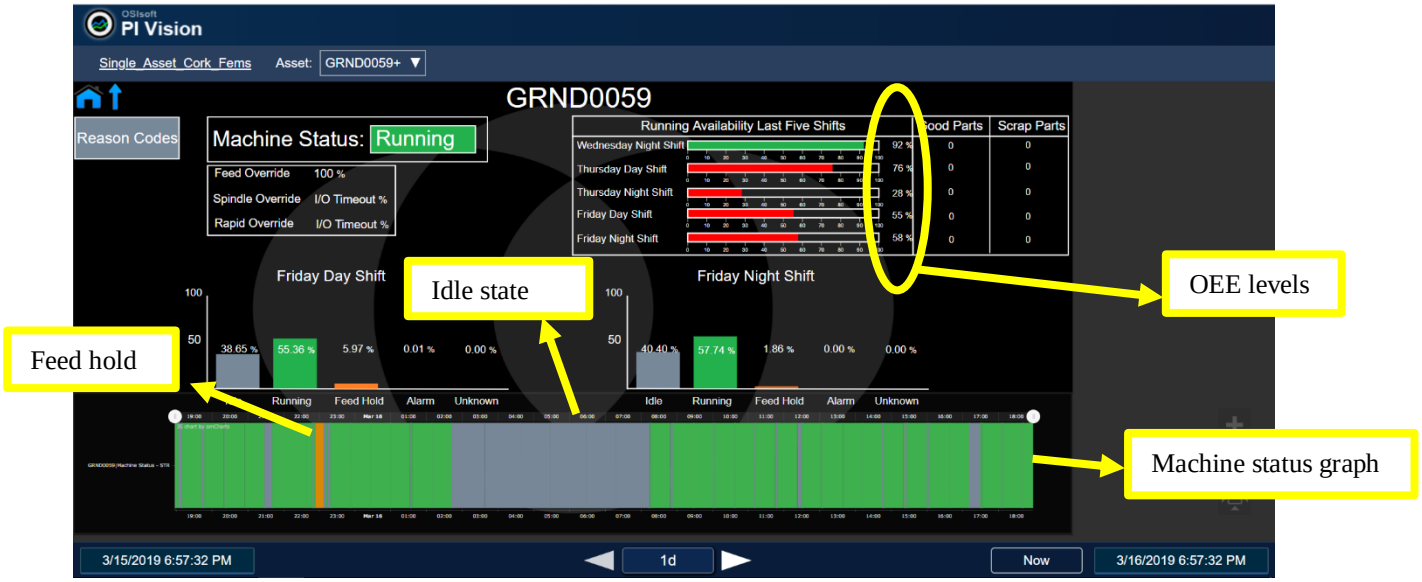


Figure 7.4-9 OEE for GRND0059 Friday night shift 15th March 2019

To investigate the reasons for the continued low OEE on this machine, we can use the reason codes logged in OSI PI. Figure 7.4-10 shows that there are no reason codes recorded for this machine in this period.



Figure 7.4-10 Unacknowledged events for GRND0059 15th-16th March 2019

Using the issue log, shown in Figure 7.4-11, we can see that there is some issues related to GRND0059. Figure 7.4-12 has filtered these dates to the period in question.

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes	Lead	Days
						Open	Closed	Escalated		Time	Overdue
GRND0059	Dress Wheel	Replace	Engineering		11-Mar-19	11-Mar-19	12-Mar-19			1	1
GRND0059	Airflow issue	Adjust	Facilities		15-Mar-19	12-Mar-19	15-Mar-19		high airflow over head	3	0
GRND0059	LTA Unit Leaking	Fix	Maintenance		15-Mar-19	14-Mar-19	15-Mar-19			1	0
GRND0059	Wheel issue	Replace	Engineering		15-Mar-19	15-Mar-19	16-Mar-19		wheel change	1	1
GRND0059	Parts uneven	Fix	Engineering		25-Mar-19	24-Mar-19	25-Mar-19		4.5t Sharpen anterior and posterior edge	1	0
GRND0059	Arbor issue	Fix	Tool room		30-May-19	29-May-19	31-May-19		parts not sticking	2	1
GRND0059	Parts uneven	Fix	Tool room		7-Jun-19	7-Jun-19	8-Jun-19		Size 5 Sigma CR Arbour parts pulled out	1	1

Figure 7.4-11 Issues logged for GRND0059

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes	Lead	Days
						Open	Closed	Escalated		Time	Overdue
GRND0059	Dress Wheel	Replace	Engineering		11-Mar-19	11-Mar-19	12-Mar-19			1	1
GRND0059	Airflow issue	Adjust	Facilities		15-Mar-19	12-Mar-19	15-Mar-19		high airflow over head	3	0
GRND0059	LTA Unit Leaking	Fix	Maintenance		15-Mar-19	14-Mar-19	15-Mar-19			1	0
GRND0059	Wheel issue	Replace	Engineering		15-Mar-19	15-Mar-19	16-Mar-19		wheel change	1	1

Figure 7.4-12 Issues logged for GRND0059 during the week of 11th of March 2019

We can see that there are four issues, including wheel change, a leaking unit and airflow issues. These all could have impacted the OEE on this machine, causing feed hold or pause states while the machine is under repair.

7.4.3. Example at GRND0054

A final example of this sort of issue with no explanation for OEE is at GRND0054. Figure 7.4-13 shows the OEE for this machine between the 3rd and 4th of April, 2019. The OEE is dwindling as the week goes on, 14% on the Wednesday day shift– falling to 7% on the Wednesday night shift. The graph along the bottom shows us the varying states for this machine; it is mostly idle and has a small percentage of feed hold and unknown states in this time frame.



Figure 7.4-13 OEE for GRND0054 3rd - 4th of April 2019

If we inspect Figure 7.4-14 we can see that there are no reasons provided for the various states that GRND0054 has experienced in the time in question, with all events unacknowledged.



Figure 7.4-14 Unacknowledged events for GRND0054

Investigating this further using the issue logging tool, we can find all logged issues for this machine, shown in Figure 7.4-15. The issue that is relevant to this time frame is the third one down, a spindle issue opened on the 3rd of April. The spindle is vital for the successful running of this machine. Understandably, the OEE will have dropped significantly as soon as this issue became known. According to the issue logging table below, this was an ongoing problem with updates spanning over two months, with the issue not being closed until the 10th of June, giving it a lead time of 68 days –which is far from ideal.

Workstep	Issue	Action	Owner 1	Owner 2	Due	Status			Notes	Lead	Days
						Open	Closed	Escalated		Time	Overdue
GRND0054	Probe issue	Replace	Maintenance		7-Mar-19	6-Mar-19	8-Mar-19		probe broken	2	1
GRND0054	Failing toe height	Investigate	Tool room	Maintenance	20-Mar-19	19-Mar-19	21-Mar-19			2	1
GRND0054	Spindle issue	Order	Maintenance		10-Jun-19	3-Apr-19	10-Jun-19		Dittle changed 30 may, changed back 31 may - needs set up	68	0
GRND0054	Failure part location	Monitor	Engineering		8-May-19	7-May-19	8-May-19			1	0
GRND0054	Wheel issue	Adjust	Engineering		23-May-19	23-May-19	24-May-19		wheel balance	1	1
GRND0054	Wheel issue	Monitor	Maintenance	Engineering		19-Jun-19			imbalance to wheels //grinding wheels wore out	0	0
GRND0054	Health & safety issue	Check dresser	Engineering		26-Jun-19	25-Jun-19	26-Jun-19		body will be hurt	1	0

Figure 7.4-15 Issues logged for GRND0054

Using the information gathered from OSI Pi and the issue log feature of the DMIN tool, managers can work to find the reason behind this spindle issue to avoid it recurring in the future.

These examples illustrate the further insights provided by cross-referencing information from existing sources, combined with the database developed through digitisation that is provided

by the DMIN tool. By managing the data in a way that it can be easily understood, such as the Issue Logging table, and matching it to other data sources that provide information about the same area can give a clear indication of the problems that are occurring.

8. Future work

The DMIN tool was developed as a proof of concept to demonstrate the prospect of digitisation of the Pulse Walk. Although this tool can be employed as a case study to investigate how and where digitisation will be used, it requires further development before it can be implemented on the wider factory floor. This chapter will explain how each part of the tool could be elaborated and improved before widespread use.

8.1. Development of Design

The desired improvements from the proof of concept trialled on the floor have been outlined in the workshop feedback, Chapter 6.3. This feedback has been taken on board during the outlining of future work for the DMIN tool. These developments are aiming to improve the functionality of the tool and assist with ease of use, focusing on the main goals of this research:

- Streamline the Pulse Walk
- To reduce the time spent on Pulse Walk
- To highlight recurring issues for waste reduction
- Improve efficiency of the production line
- Improve communication between staff and managers

This chapter will discuss future work required to implement these changes and realise the full potential of the DMIN tool.

8.2. Breakdown of project

The project has been trialled on both iPads and screens on the factory floor during Pulse Walks. This means there are two options for the development of the DMIN tool, a native application (app) that will be supported on an iPad or other handheld devices, or a web application (web app) that will be supported through a web browser on a computer. The workshop concluded that the tool would be ideally used on screens, supported through a connected computer. Bearing this in mind, an investigation was still carried out to determine whether a web app or iPad app would be best suited for the development of this tool.

8.2.1. Native Application

This would be developed in iOS or Android depending on the supporting device. For the medical device manufacturing company, iOS and Swift would be used to support app development for the company issued iPads [71].

This type of app is more beneficial for 'on-the-go' customers; push notifications can be used to share information. This is not relevant to what the DMIN tool is trying to achieve- the tool will be used on Pulse Walks at stationary points to share information amongst a group of people.

Furthermore, this type of application is not transferrable. This means that if an app is built for iPads, it cannot be deployed onto the interactive web-enabled screens unless they are apple compatible, which adds another layer of complication to development.

They are hybrid apps which can be developed, such as Xamarin, which uses C# to code for Android, iOS and Windows devices. However, these apps have generally slower performance and are difficult to customise to suit each platform requirements [72].

8.2.2. Web Application

Web applications are supported through a web browser, such as Chrome, Safari or Firefox. Web apps do not have to be downloaded onto a device, so do not take up storage space. Furthermore, web apps do not require approval from app market places, nor do they have to adhere to operating system protocols in the way that native apps do [72].

They can be developed using a Java backend and JavaScript combined with CSS and HTML to build a dynamic front end. The front end is the visible part of the web app that the user interacts with; all fonts, dropdowns and forms are built using HTML, CSS and JavaScript. The back end consists of an application, a database which is stored on a server.

Developing the tool as a web app allows for a standard template to be created, which can then be adapted for each step of the Pulse Walk, which will require specific information for that stage.

This research has suggested that a web app would be more suitable to the requirements of the DMIN tool; for this reason, it has been chosen as the basis for future development.

8.3. Issue Logging

The issue logging aspect of the DMIN tool will be improved. The current setup which uses a google sheets document will be upgraded by using a web app design so that the data can be entered into a table and saved to a database. This table will be set up in the same way as the current board and DMIN tool, including the checklist, which is specific to each board. This will be followed by an issue logging table, with the added columns deliberated from the workshop feedback in Chapter 6.3.3, shown in Figure 6.3-3. Developing this table using JavaScript means that it can be coded to include sorting capabilities of each list, in addition to filter options in the same vein as the Google Sheets document.

This style will be replicated to build the Idea logging page, in the same way that it was made for the proof of concept DMIN tool. Another table will be featured in the tool for communication, as per the workshop feedback. This is discussed further in Chapter 8.5.

8.3.1. Adding Updates

Using JavaScript allows updates to be added to existing entries, so original data is not erased in the event of further work on an issue, as discussed in Chapter 6.3.3. Furthermore creating a web application with a front end developed in JavaScript, and a back end coded in Java allows for automated email notifications when there are updates made to the issue log table. These emails can be sent to any owners containing information about the issue. Using this same technology, it can be set up to create a ticket in Maximo and Safety if required. This information can be posted to the desired location using a representational state transfer (REST) Application Programming Interface (API) call [73].

8.3.2. Colour Coding

Colour coding was brought up during the workshop as a method to highlight overdue issues. A traffic light system was discussed during the workshop, but this has the possibility of over-complicating the table with colour. Instead, any issues that are less than three days old will not be coloured. Issues more than three days old will be coloured yellow and any older than a week will be coloured orange. This will draw attention to the issues that have not yet been closed and require immediate attention.

Another suggestion from the workshop was an extra column to be added to the issue log table that indicates the machine in questions' status. This can be retrieved from OSI Pi and will be highlighted as green if running, or red if the machine is down.

Orange and yellow will be used to illustrate the age of issues instead of the traffic light system suggested during the workshop. This is because using a standard traffic light colour scheme of green, amber and red could interfere with the cells highlighting machine status, which are green or red.

Colour coding of rows and cells can be achieved through JavaScript coding at the front end of the web application. An IF statement can be used to determine the contents of the cell, whether it says 'Running' or 'Down'. This can then decide if the cell is to be coloured red or green.

To colour a row of the table based on the age of the issue can be achieved in the same way, using an IF statement to determine the time between when the issue was opened and the day's date. If this interim time is more than three days, the row will be yellow. If it is more than seven, it will be coloured orange.

8.3.3. Checkboxes

It was decided at the workshop to use a checkbox to signify an issue is closed. This can be included in the issue logging table, under the closed date column. When the checkbox is ticked, it will record the date and time that the issue was logged in the database. This checkbox can be used to filter all issues to show only the open ones during the Pulse Walks, by checking the value of each checkbox and only showing those that are not ticked. In programming, this can be determined by inspecting if the box is ticked. As it is a Boolean value, it will return 'TRUE' if ticked or 'FALSE' if unticked [74]. An example of the code snippet for this is shown in Figure 8.3-1.

```
var x = document.getElementById("myCheck").checked;
```

Figure 8.3-1 Code snippet for finding checkbox value

Checkboxes are already used as part of the issue log table checklist. As discussed in the workshop, these are to be recorded and sent as a weekly report to the Value Stream Manager (VSM). By using a web application front end, this checklist can be set up as a table in JavaScript. The checklist that is recorded for each day will be saved into a database. This data can be retrieved on a weekly basis and collated into a graph to illustrate if there was any missing during the Pulse Walks that week.

8.4. Web Application Setup

The web app will have multiple sources contained within it, including the issue logging and selected data sources. Including each source embedded into one page will reduce the need for moving between screens, which may add time to the Pulse Walk as information is loaded.

The tool will be available as a user interface (UI), developed as a web application, embedding each data sources into it using HTML tags. Using Inline Frame (Iframe) element tags in HTML allows for webpages to be shown within another web page. This will allow for the data sources to be displayed on the homepage. The Iframe can also be set up with a scroll bar, separate from the main page, to allow for further viewing of the data source. The Iframe uses the desired sources' URL to embed it, which means the same URLs used for the proof of concept of the DMIN tool can be used here. An example of how to embed a URL into an Iframe is shown below in Figure 8.4-1 [75].

```
<iframe src="URL"></iframe>
```

Figure 8.4-1 Example of Iframe code to embed a webpage into another webpage

These frames can be adjusted in height and width to determine the size of them on the home screen. Iframes have many attributes that allow them to have a range of features, such as 'allowfullscreen' which means that the data source can be shown in full screen. Other features

include ‘importance’ which designates download priority, and this means that higher importance can be given to features that are required immediately on the Pulse Walk so that they load first.

The final and most important note about Iframes is that they are compatible with a vast range of browsers, with high levels of compatibility with Google Chrome, the standard option used in the medical device manufacturing company in which the DMIN tool will be used [76]. Although Iframes can be used to include sources from other sites, increased use of Iframes leads to decreased speed. This should be kept in mind during development and thoroughly tested before deployment to ensure loading time is within the desired limit, to keep the Pulse Walk time down.

Iframes have posed security risks to websites in the past; in 2008, hackers infiltrated many people’s home computers though fraudulent Iframes embedded into websites [77]. It is vital to remember security when creating a web app that will contain so much production information for the factory in which this research is based. However, this web app will be published on an internal network that already has ample cybersecurity. Furthermore, all information is shown in the web app is coming from other sources within this network, so there is no interaction with the external internet where there would be higher risks of an attack.

8.4.1. Data Sources

As mentioned above, to improve screen loading, time data sources will be included embedded into the home screen. The data sources that will be included are as follows:

- OSI Pi for OEE shown in Pi Vision.

  OEE is the overall equipment efficiency of the machines and indicates the percentage of time that a machine has been running for. This data is saved in OSI Pi, and shown through a dashboard on Pi Vision.

- Qlik Scrap dashboard

  This dashboard contains the scrap information for the site, and can be filtered to show the FEMs Value Stream. This dashboard has daily, weekly, monthly and yearly filters.

- Qlik OEE for FEMs

  The information shown in this dashboard is a donut chart that indicates the reason codes used for when machines are logged as not running. These reason codes are saved in OSI Pi, as mentioned in Chapter 7.4.

- Issue logging table

  This is the digitised issue log that has been developed to replace the white boards used on the factory floor during Pulse Walks.

- Qlik Issue Insight dashboard

  The data from the issue logging table is used to create this dashboard, which shows how many issues are open, the number of each issue and the lead times, among other things. This is discussed in Chapter 7.2.

- Maximo issues

  Maximo is software that is used to store maintenance work orders.

- Energy data

  Energy data will be introduced to the Pulse Walk, this information is not included at present.

- Reprocessing

  Reprocessing relates to ages work orders that have been on hold, and are now being reintroduced to production.

- MRRs in process

  Material Review Reports (MRRs) describes batches that have been sent for reworking.

- Excess WIP locations

  This describes the location where excess batches on the floor are stored.

- Day by the hour targets

  These targets outline the daily plan for production.

- Safety

  Safety is a type of software that is used to record good workplace behaviour, such as ‘good saves’.

- Curve

  Curve contains the Key Performance Indicators (KPIs) for the Value Stream.

Each option should be set up to show the relevant information for the specified step of the Pulse Walk. This can be done by filtering on Qlik, or product family on OSI Pi, which is shown on Pi Vision. The idea logging table and communication sheet will also be included at each step of the Pulse Walk.

8.5. Pulse Walk Screens

The aim of this home page is to have the information clear and concise so that any observer can understand it quickly. If the user requires further information, each data source should be expandable to open it and look at the information in greater detail. As there is a great deal of data to be shown on each screen, it can be separated into pages. The web app can support multiple pages to make it easier to read and understand all of the data involved at each step.

The first page of the web app will contain the data sources that are featured in the Pulse Walk discussions, the checklist and issue logging table, the Qlik issue insight dashboard, Qlik OEE dashboard and Maximo showing the open tickets. These contain priority information that are the primary sources of discussion at each Pulse Walk step. Figure 8.5-1 shows a mock-up of how this page will look, providing each data source included with enough space so the information can be read clearly and comprehended with ease. The top left shows the checklist for the Pulse Walk at this step, which will be a table built in JavaScript connected to a database, as mentioned above in Chapter 8.2. There are three columns of checkboxes instead of the original six. This is because there are three Pulse Walks in a day, meaning there will be no need for any more than this amount as the ticked boxes will be recorded and erased before the next day’s Pulse Walk. The Qlik issue insights dashboard is in the top right section. It will have a scroll option so that the rest of the dashboard can be viewed. The issue log will also be a table

built in JavaScript, with scroll capabilities and a connection to the same database as the checklist, but will use a different table. The OEE doughnut chart from Qlik is shown on the bottom left. This is currently only used at the Grinders stage of the Pulse Walk as these are the only machines currently connected to OSI Pi. As the factory moves forward to connect all machines to OSI Pi, this will be a necessary feature on each Pulse Walk screen. The bottom right shows the Maximo data source. It should be noted that this is a generic example of what a Maximo page would look like.

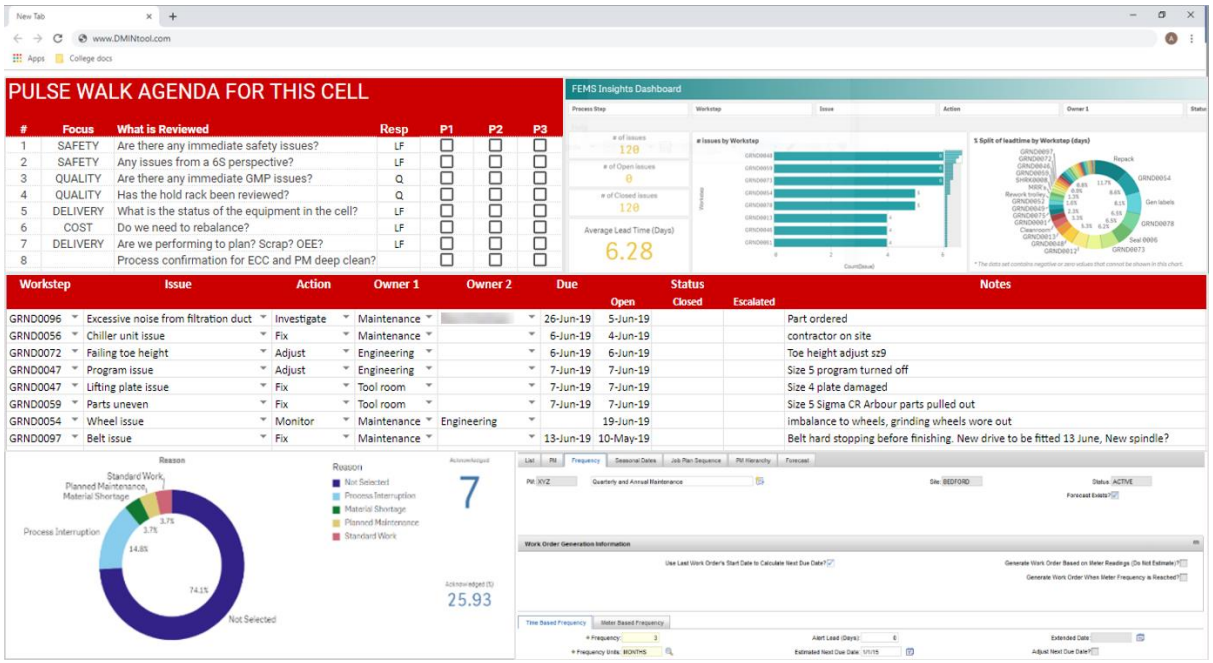


Figure 8.5-1 First page of DMIN tool web app

The second page of the web app will contain the remaining data sources, OEE from Pi vision, Qlik scrap dashboard, day by the hour (DBTH) targets, reprocessing, MRRs in process, scrap from reprocessing, hold and energy data. The data from Pi Vision will be included in an Iframe, as will the Qlik dashboard. DBTH targets will be shown in the next row. This information can be retrieved from the Value Stream Manager (VSM). DBTH targets are currently stored as an Excel sheet. This can be visualised as a Qlik dashboard and shown on this page of the DMIN tool. During the workshop, it was suggested that this information should be printable for distribution if necessary, so the table should have a printer option for this chart. The information regarding reprocessing, MRRs in process, scrap from reprocessing and hold will all be included in a tabular format. This information will be sourced from OMS, which is an Order

Management System and is used to store production information. Figure 8.5-2 shows a mock-up of this page. The top left shows the OEE on Pi Vision from OSI Pi. To the right of this is a representation of the Qlik scrap dashboard. The bottom row shows what the DBTH target will look like in Qlik format. This is followed by the tables for Reprocessing, MRRs in process, scrap from reprocessing and hold information.

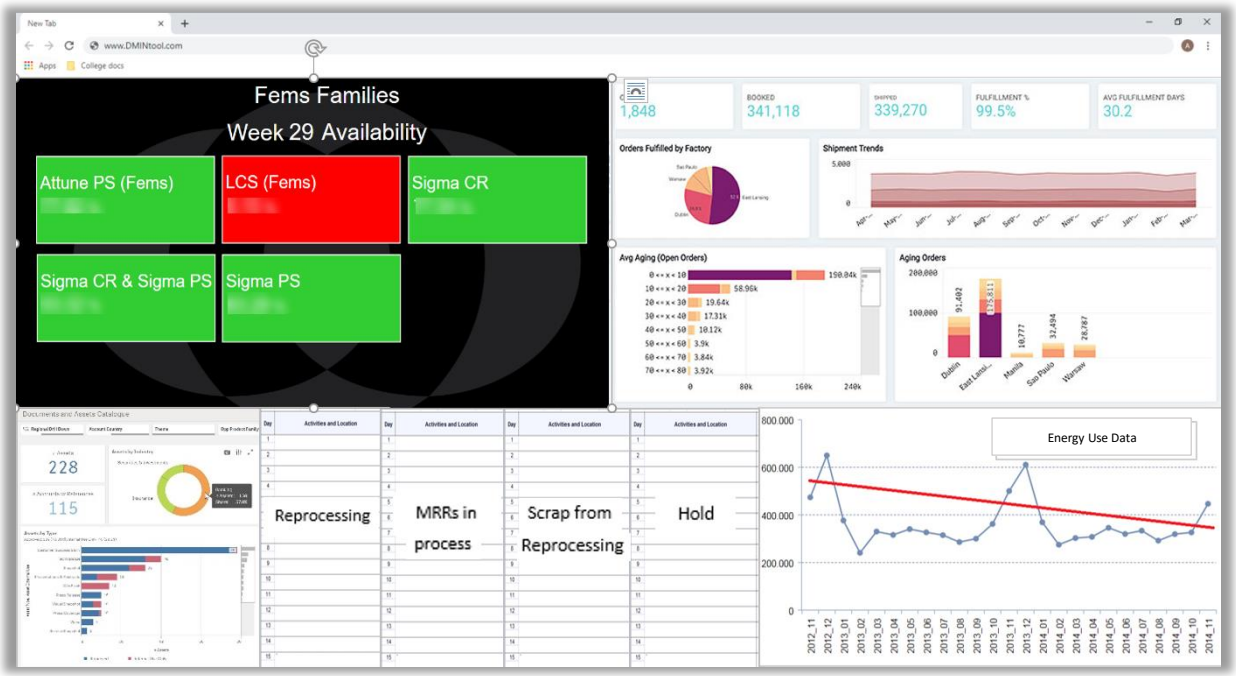


Figure 8.5-2 Second page of DMIN tool web app

Energy data will be included in this sheet, there is currently an energy dashboard for the whole factory for the medical device manufacturing plant, and they are moving towards having Value Stream specific analytics for energy use. As the factory moves towards achieving this, the data will be included on the DMIN tool screens to draw attention to energy use and improve behaviours as discussed in Chapter 6.3.2. This energy data should be included as a graph showing usage, with an indication if there have been improvements from previous weeks. The chart on the bottom right of Figure 8.5-2 shows a generic energy use chart, where the factory specific one will go.

The third page of the web app will be used as a communication page, with the idea log and space for any information to be shared between staff during shift changeovers. The

communication sheet that was brought up to be included during the workshop can be developed in the same style as the issue logging table, using JavaScript to make a data entry space. This can be structured as a simple table with space for operators and managers to note down any essential information during shift changeovers. This data will not need to be recorded in a database as it is simply used for sharing pertinent information at the time. If any issues arise from this, they will be recorded in the issue log as standard. An example of this is shown in Figure 8.5-3, they will both be scrollable tables in the same format at the issue log table so there is continuity throughout the app. Furthermore, each table has been colour coded to avoid any confusion. The Idea log table will be connected to a database and will send email updates to managers, in the same way as the issue log table will, alerting them to the new entry.

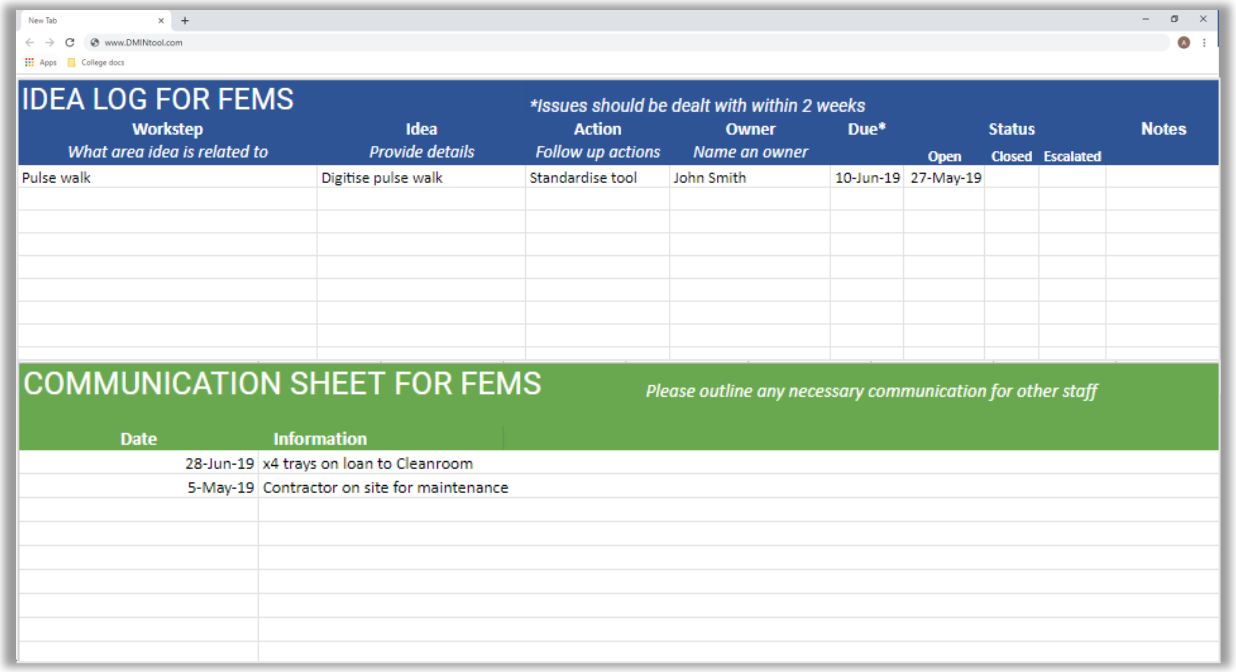


Figure 8.5-3 Third page of DMIN tool web app

Separating the web app into three sections allows for one page to focus on issues during the Pulse Walk, the second to share other important production information and the final one to be used for communication across the Value Stream. Several methods can navigate these sections; for example, each section could be opened as a separate page when a button is clicked. This method could lead to unwanted delays for loading time as the page will have to be reloaded

each time it is accessed. A more suitable way for this tool to navigate between these screens would be to include them as 'tabs' at the top of the page. This means that all charts will load when the page is opened, and there will be no wait time for charts reloading in between navigation. Furthermore, the tabs will always be visible at the top of the screen to make it easy to move between data sources.

8.5.1. KPI board

As discussed at the workshop, the KPI board will have a different set up than the first four boards as it will provide different information. The KPI screen will not have a checklist as it is not required at this step of the Pulse Walk. The KPI screen will act as an overview of the whole Pulse Walk. It will include additional data sources such as Safety, Curve and Excess WIP locations on top of the other data sources included in the first four screens. The format of this screen will follow the same style as the other Pulse Walk screens, with the first one focusing on issue logging and analyses of this data. The second will show further information about production such as reprocessing information, MRRs in process and excess WIP locations. The third screen will have the same communication tables shown above in Figure 8.5-3.

8.6. Attendance

Attendance was brought up at the workshop as there are currently issues with this matter during the Pulse Walks. At present, there is a mix of problems arising such as too many people taking part in the Pulse Walk, but also that not every department is represented as they should be. A roll call was suggested for the Pulse Walk to improve this. Another way to do this would be for the Pulse Walk leader to tick off a list of departments if they are represented at each step to avoid wasting time calling out names. However, this could distract the Pulse Walk leader from the discussions taking place as they would be focused on the attendance roll. Furthermore, this would require them to have a good knowledge of everyone's department in order to confirm attendance without asking them, as this could interrupt any conversations taking place.

As this would be time-consuming to carry out at each step, card scanning was suggested instead. As all staff members in the factory carry ID badges with them at all times, these could be used to scan attendance at each step of the Pulse Walk. Card scanners would have to be installed at each step of the Pulse Walk, so that staff can scan their badges quickly before the

meeting resumes at each screen. Multiple vendors sell this attendance tracking technology, as it is popular in schools and universities:

- Anseo Suite, uses biometrics or ID cards to record attendance [78]
- BarcodesEDGE Time & Attendance tracking solutions [79]
- SEAtS Software wall mounted & portable card/biometric reader devices [80]

When the card is scanned, it should record the staff's name and department along with the time it was checked. This could be saved to a database for review to ensure the correct attendance. The managerial team could examine this database at the end of each day or week, at their discretion.

One thing to bear in mind for employing this technology is to ensure that it is a smooth process, and there is not a queue of people waiting to scan their badge as this will add delays to the Pulse Walk.

8.7. Qlik Dashboard

The Qlik issue insight dashboard that has been developed to highlight the recurring issues for each step currently does not use live data. Currently, the data from the issue logging table on Google sheets is downloaded into an excel document which is then used to populate the Qlik dashboard.

This process will be automated so that the dashboard is as up to date as possible. Data retrieval can be set up as a timed process to refresh the information after each Pulse Walk. To pull live data, an API call will be requested to retrieve the data from the server and use it to populate the dashboard [81]. This should be done after each Pulse Walk, to load the newly entered or updated data to the dashboard. Figure 8.7-1 describes this connection. The data is entered into the issue logging table, and it is saved into a database. The Qlik server accesses this database, requesting information from the server to populate the dashboard, which is shown as part of the first screen as described in Chapter 8.5

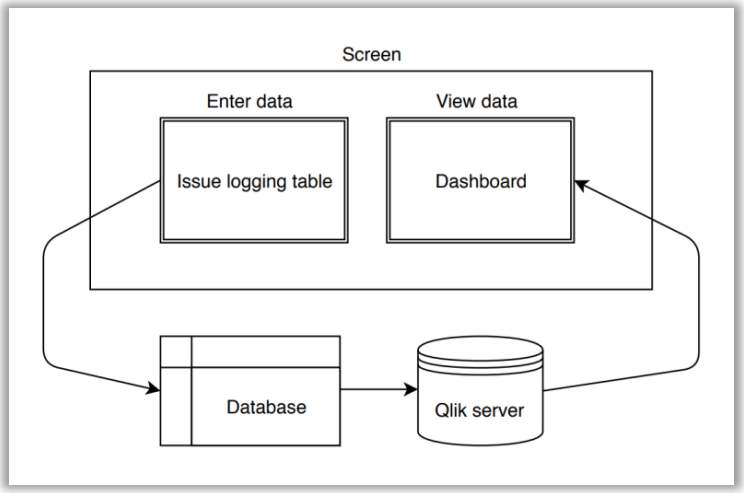


Figure 8.7-1 Breakdown of data retrieval for Qlik dashboard

8.8. Technology

The tool will be developed for use on screens, as trialled during this research. Ideally, it will be used on web-enabled interactive screens, used with a compatible pen and physical or on-screen keyboard. This will be up to the discretion of the factory as the price involved in purchasing five of these screens is significant, described in Table 8.8-1. This table describes the range in prices for various brands of interactive screens available on today's market. These prices have been averaged and multiplied by five to determine the cost of installations for the full Pulse Walk, with the total at nearly €10,000.

Brand	Name	Size (inches)	Price
Elo	E218847 Elo 5502L	54.6	€1,815.96
Viewsonic	IFP5550 I	55	€1,691.97
Dell	C5518QT	55	€2,929.43
Benq	RM5501K	55	€1,807.41
HP	LD5512	55	€1,007.99
			Average price = €1,850.55 5 screens = €9,252.76

Table 8.8-1 Price comparison of interactive displays

These interactive screens will replace the current screens that are on the factory floor. These screens are connected to a computer that is used to control what is shown on them. The web application will be shown on the screen, via the computer, which will be connected to the company network via Ethernet, allowing secure access to the desired sites such as OSI Pi and Qlik. Using a wired network connection such as Ethernet protects against Wi-Fi blackspots which have been experienced on the factory floor in some areas.

A cheaper option to create an interactive screen is to use a wireless keyboard with a mouse pad, as was done during the trials. Although this can be cumbersome to manipulate, the keyboard can be plugged into the existing screens for instant use with the developed web app. There is a range in price for these keyboards as there is a range in quality, shown in Table 8.8-2. Ideally, one that would be used with this tool would be lightweight (less than 500grams) and a high wireless transmission frequency of 2.4GHz or more to facilitate rapid movement and data entry during the Pulse Walk. The table below has priced up the average cost of purchasing five keyboards, as one will be stationed at each Pulse Walk screen at all times so that the data can be perused at all times of the day.

Brand	Name	Price
Logitech	K400 Keyboard	€55.34
Rii	RT504 Wireless Handheld Keyboard with Touchpad	€26.83
AmazonBasics	K4R-US Wireless Keyboard	€28.00
Microsoft	N9Z-00006 Wireless All-in-One Media Keyboard	€48.97
Arteck	HW197 Wireless Touch TV Keyboard	€27.00
		Average price = €37.23 5 keyboards = €186.14

Table 8.8-2 Price comparison of wireless mouse and keyboard

There has been a ‘smart pen’ developed that can make screens touchscreen by connected a receiver to the side of the monitor. These products, XN810 and XN811, were released in 2013 by Yifang for $80 (around €70) but is no longer available commercially [82]. The two available options worked on an 18 inch or a 26-inch screen. If a product like this was developed to be used on a 55-inch screen, it could be implemented as part of the DMIN tool in place of a wireless mouse and keyboard.

8.9. Implementation

The tool will be used in the same way as the boards are currently, they will be positioned as decided during the workshop, as outlined in Chapter 6.3.1. The setup of the screens allows for anyone to access the information, including the issue log. Although there was a discussion about including a login system for the issue log to keep track of who is updating problems, this could cause unnecessary time delays. Furthermore, there is no system in place for this at present in the factory, to add this feature could annoy the workers. For these reasons, the login feature has been excluded from the DMIN tool. The screen will be openly accessible to all staff so everyone can benefit from using the tool.

Regular check-ups should be carried out to ensure the DMIN tool is being used correctly by all members of staff. These should highlight if anyone is misusing the tool. Training can be put in place if anyone is using the tool incorrectly. All staff must understand how to use the tool and the benefits it poses. For the tool to work correctly, the information must be entered correctly; thus requiring staff to be educated on how to use it.

8.10. Advancing 'State of the Art' in the Field

The DMIN tool proposed in this research will be a 'one-stop shop', providing the user with all necessary information relating to the FEMS Pulse Walk. Although the tool outlined is a proof of concept, it proves that hosting production information for a manufacturing facility can improve the efficiency of a Pulse Walk. The DMIN tool can be used as a basis for digitising other processes in the factory as it allows rapid access to information in a succinct and organised manner by integrating technology and IoT onto the factory floor.

The research presented here has proved that the tool has the ability to drastically improve the Pulse Walk, to make it more streamlined and effective by cultivating a refined process that is reviewed regularly, such as the Lean principle of Kaizen suggests should be done to continually improve processes. Employing technology in this way allows the factory to move away from manual processes such as using paper or whiteboards to share and log information. This minimizes the dependency on office supplies such as paper, pens and whiteboard markers and improves the efficiency of how information is shared.

The DMIN tool will advance communication between staff members at various levels, not only will the users be able to learn from previous errors through the database of issues but they will be able to follow up with the member of staff who dealt with similar issues in the past. Fast tracking this connection between staff can save time and the pedantic nature of asking already busy staff who was involved on solving an issue at some point in the past.

Research into One-stop shops indicate the need to analyse the needs of the user, and tailor the experience to suit what is required [83]. This research has done exactly that, it will combine information from a range of data sources, making the Pulse Walk process more streamlined with specific information for the industry partner. It has been developed to encapsulate only the required information, and to present it in a useful manner. Upon completion, this project has provided a simplistic example of the architecture required to digitise the Pulse Walk and a guide to the process involved. The research that has outlined the necessary data sources to include, and in which way they should relate to the other manufacturing information sources. This prototype proof of concept has outlined the basis for creating a digital one-stop shop that can be utilised across the factory in a range of different processes. The DMIN tool is the stepping-stone between the previous manual process, and the digital future to support smart manufacturing and IoT while employing Taiichi Ohno's principles of Lean production to improve efficiency and communication between all levels of staff.

9. Discussion

This research set out to improve the Pulse Walk in a medical device manufacturing facility. A proof-of-concept tool, developed to replace whiteboards on the Pulse Walk tool, evolved to become an information hub for many different factors of production data. The tool is referred to as the Digitised Manufacturing Information Nexus, or DMIN tool.

The DMIN tool was developed following the background research carried out to investigate Lean methodologies and how they can be implemented to improve production, as well as digitisation to move towards the era of Industry 4.0.

9.1. Review of DMIN Tool

At the conclusion of this research, the DMIN tool has been trialled as a proof-of-concept. This consists of a PDF, available through scanning a QR code with an iPad, and on screens positioned on the factory floor. The PDF acts as a menu page offering various data sources, curated from survey feedback discussed in Chapter 4.5.3. These data sources deal with machine OEE and scrap. Additionally, a digitised version of the issue logging board has been developed as an online spreadsheet, with specific Issue Codes outlined for each step of the Pulse Walk. Drop-down lists of standardised options provided for Work step, Action and Owners, enable auto-filling entries to streamline this aspect of the Pulse Walk. Similarly, all date entry cells have been formatted in the same manner enabling comparisons within collated data. Data recorded from Pulse Walks over the course of several months has been recorded into this issue logging table. With data collection standardised and structured, a Qlik dashboard has been developed providing analytical insight into the issues being recorded.

The DMIN tool was efficaciously used on the factory floor with trialling at on different steps of the Pulse Walk. This helped gain understanding of its usefulness in logging issues and providing data source support to benefit employees. The downside of the DMIN tool was that it was cumbersome to use so not as user-friendly as necessary for streamlined navigation between pages, and issue logging. This meant that it was difficult to determine if this iteration of the DMIN tool could improve the speed of the Pulse Walk.

Despite the early challenges encountered when using the proof-of-concept during the Pulse Walk, the DMIN tool still proved to be advantageous. As outlined in the Use Case in Chapter 0, this tool introduces a method of searching historical entries in the issue log. The Issue Insight dashboard makes it easier to understand the spread of issues for the Value Stream as a whole, as well as each step of the Pulse Walk, so can assist in investigating the OEE of machines. In the long term, the DMIN tool has the capability of improving the energy efficiency of the medical device manufacturing company, by reducing the number of defective batches requiring rework. This can be achieved by using the historical issue log to monitor recurring problems, and complete root cause analysis to understand and eradicate the issue. In addition to the benefits discussed above, this tool improves information access for staff involved in the Pulse Walk by eliminating the need for print outs of production data since this is available through the DMIN tool.

Future work already outlined for this tool will improve the Pulse Walk procedure. Developing a fully functioning user-friendly interface will make the DMIN tool more comfortable to use, with better navigation between production data. When the tool is fully developed and wholly integrated into the factory, it should work seamlessly with staff during the Pulse Walk. With these improvements, time spent on the Pulse Walk should reduce to be in line with the desired duration of around 20 minutes. However, while this tool will improve information access and the speed of entries into the issue log, other time delay factors are often human which machines cannot overcome. Attention must continue to be given to keeping the Pulse Walk discussions as 'Lean' as possible to avoid any unnecessary delays.

Reduction of waste in the production process brings the DMIN tool in line with Lean methodologies; the aims of which are to reduce inefficiencies, continuous improvement and respect workers' capabilities.

The digitised Issue Logging table can assist the DMIN tool can minimise waste on the Pulse Walk. The tool can be used to track recurring problems, which will support early recognition of issues. By recognising an issue is occurring at the early stages, it can be rectified before it affects the output of the process line. An example of this would be if there was a faulty or damaged machine that was resulting in imperfections on parts produced. The earlier this problem is recognised and dealt with, via the issue tracking log which would provide details of a solution to the issue, the less damaged parts that will be produced thus minimising waste or resources and time as the parts will not need to be scrapped or reworked.

The Issue Logging board allows staff to see what issues are being worked on and by who; this is similar to Kanban in Lean. This format lets everyone see who is involved in what, which is especially useful if someone has questions about an issue. The historical database of the Issue Log will make it easy to trace who dealt with issues in the past, and how the solution was found. Having this clear description of issues will assist with new staff learning about the processes, what common problems arise and how they can be solved.

In keeping with Lean philosophies that respect a worker's knowledge of processes, since inception this research has been concerned with getting feedback from the staff on the factory. It was vital to learn from the experiences of operators, managers, and Team Leads as they have a hands-on perspective of the Value Stream and the Pulse Walk. To better facilitate feedback, and in response to survey and initial demonstration feedback, the DMIN tool incorporates a platform for staff to share feedback, the Idea log. Introducing the DMIN tool to production across the factory, helps align the medical device manufacturing company with the aspirations of Factories of the Future (FoF) to integrate innovative technologies to enhance manufacturing.

A further feature of FoF and the DMIN tool is the embodiment of progression towards more environmentally friendly production. Availability of production information reports online reduces both paper and ink improving the environmental impact of the Pulse Walk. Furthermore, as outlined above, the DMIN tool has the capability of improving the factory's energy efficiency through issue tracking facilitating continuous improvement.

9.2. Communication

Prevalent throughout this project has been challenges in communication and articulation of ideas. Some of this can be related to the knowledge gap between engineers on the innovation team assisting with this research, and the associates and team leaders working on the FEMs production line. Attending multiple Pulse Walks assisted in bridging this knowledge gap, coupled with asking Pulse Walk staff what they wanted to see as part of the tool.

Perhaps the greatest struggle for this researcher was articulating what the project actually achieves. In part this was due to mismatched definitions of the terminology being used causing confusion and misunderstanding for various people involved. Taking the time to understand the numerous aspects to the Pulse Walk assisted the researcher in learning the correct

terminology, ultimately improving communication with staff and aiding clarification of the specific goals of the project and agreeing how these could be achieved.

When the feedback survey from the project demonstration was emailed to those involved, care was taken to explain the methodology and goals of the project appropriately. This was vital to ensure that there would be no confusion for those participating in the survey, to maximise the response numbers and gain the most data to work with.

An interesting aspect of implementing this project on the factory floor was getting it accepted by prospective users. It is important to take into account the generational gap amongst employees. Younger employees, that is those of a 'digital generation', are likely to have grown up with technology, have a sound understanding and knowledge of how to use it are perhaps more accustomed to using it daily. In contrast, more mature associates may not be as familiar when it comes to working with technology, and some may have little to no understanding of it. This lack of knowledge may provoke embarrassment or anxiety around using the technology presented in this project, ultimately leading to avoidance. To pre-empt this outcome, the project has been carefully explained to everybody during all demonstrations, trials and the workshop. The goals have been reiterated constantly throughout development to avoid them becoming skewed or experiencing any scope creep. When this project is fully implemented and rolled out on the factory floor, it will require all staff to be trained in how to use it effectively and efficiently to maximise the benefits of it.

9.3. Conclusion

This research posed the question, "Does digitising improve efficiency in manufacturing?"

This research has presented a tool to improve the Pulse Walk in a medical device manufacturing company. The proof-of-concept demonstrated the possible capabilities of implementing such a tool across the factory, assisting the factory in building on the current Lean strategies already in place while also introducing new strategies to reduce waste. The tool is in line with the aspirations for the future of manufacturing as we enter the era of Industry 4.0. Although the proof-of-concept is not a fully functional version of this tool, steps for future work have been outlined to show how the tool can be developed maximise its usefulness. This research combines the goals of Industry 4.0 by utilising Smart Manufacturing while maintaining the

Lean mentality of respecting workers. It has innovated a manufacturing procedure but not used digitisation to replace any jobs in the factory. Rather the DMIN tool employs digitisation responsibly in a manner that improves the jobs of staff at each level of the factory.

The DMIN tool reduces inefficiencies in the Pulse Walk by digitising the issue logging table to improve the speed of entries, as well as providing access to the selected data sources on the factory floor. The DMIN tool will also reduce inefficiencies in production by highlighting recurring problems that can be rectified before causing more setbacks for subsequent batches. Highlighting where issues are commonly occurring focuses attention to that area so that investigation can take place and adjustments made to those aspects of production causing difficulties facilitating continuous improvement. So to answer the research question; yes, digitising can improve efficiency in manufacturing.

Although this is true, it is important to reflect upon the caveats of digitisation that have been experienced throughout this research. For example an important factor for the success of integration of technology is to ensure that the staff using it are comfortable doing so. Furthermore, adequate training is necessary and must be regularly updated to make sure that the technology is being used in the best way possible. Taiichi Ohno's lessons from Lean manufacturing highlight the importance of listening to the workers, and this must be kept in mind as well [14]. Continued communication with staff on the factory floor will aid the managers to gain insight into any improvements that could be made to processes, such as the Pulse Walk.

Although the DMIN tool was well received, it was acknowledged that it was not a very user friendly interface due to the manner in which it was developed. Now that the concept has been proven to be useful on the factory floor, it can be developed in a more streamlined approach. The methods to do this have been outlined in this thesis as future work for the project. The key features are that the technology must be useful, fast to load and provide the necessary information in a succinct way, to avoid overloading the user with confusing data.

Overall, this research has been a success. The DMIN tool has highlighted the flaws in current practises in the manufacturing facility. The industry partner has supported the development and trial of this tool, taking care to understand the process and offer assistance throughout the process. The research and development of the DMIN tool has outlined the downfalls of current systems in place for the Pulse Walk, it has also offered a solution to improve the problems that

are currently experienced. The tool has been well received during trials and the manufacturing facility are keen to continue to invest in this digitised solution to streamline the Pulse Walk, and possibly other processes in the future.

REFERENCES

[1] H. Y. Ng, P. S. Tan, and Y. G. Lim, "Methodology for Digitalization – A Conceptual Model," in *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2018, pp. 1269–1273, doi: 10.1109/IEEM.2018.8607457.

[2] *The Digitisation of Everything*. Ernst & Young LLP, 2011.

[3] J. Golovatchev and O. Budde, "Next Generation PLM - An Integrated Approach for the Product Lifecycle Management," in *International Conference on Comprehensive Product Realization*, 2007.

[4] Y. Xin and V. Ojanen, "The Impact of Digitalization on Product Lifecycle Management: How to Deal with it ?," in *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 2017, pp. 1098–1102, doi: 10.1109/IEEM.2017.8290062.

[5] European Commission, "Key enabling technologies," *Factories of the Future*, 2018. [Online]. Available: http://web.archive.org/web/20191107185137/https://ec.europa.eu/info/research-and-innovation/research-area/key-enabling-technologies_en. [Accessed: 03-Nov-2018].

[6] J. Bicheno and M. Holweg, *The Lean Toolbox*, Fourth Edi. Buckingham: PICSIE Books, 2009.

[7] United Nations, "Convention on Climate Change: Climate Agreement of Paris.," pp. 1–27, 2015, doi: 10.1017/s0020782900004253.

[8] E. Worrell, L. Bernstein, J. Roy, L. Price, and J. Harnisch, "Industrial energy efficiency and climate change mitigation," *Energy Effic.*, vol. 2, no. 2, pp. 109–123, 2009, doi: 10.1007/s12053-008-9032-8.

[9] P. LeanKit, "Lean Methodology | LeanKit." [Online]. Available: https://leankit.com/learn/lean/lean-methodology/. [Accessed: 06-Aug-2019].

[10] D. J. Lu, *Kanban, Just-in-Time at Toyota*, English tr. Tokyo: Productivity Press, Inc., 1985.

[11] Y. Sugimori, K. Kusunoki, F. Cho, and S. Uchikawa, "Toyota production system and Kanban system Materialization of just-in-time and respect-for- human system," *Int. J. Prod.*, vol. 15, pp. 553–564, 2007, doi: 10.1080/00207547708943149.

[12] B. Boatclub, "Luxury Tungsten," Ireland, 2017.

[13] J. Shook, "How to Change a Culture : Lessons From NUMMI," vol. 51, no. 5, 2010.

[14] J. F. Krafcik, "Triumph of the lean production system," *Sloan Manage. Rev.*, vol. 31, no. 1, pp. 41–52, 1988.

[15] A. Romeo, "Kanban," 1988.

[16] M. Rouse, "What is Kaizen (continuous improvement)," *TechTarget*, 2019. [Online]. Available: https://searcherp.techtarget.com/definition/kaizen-or-continuous-improvement. [Accessed: 04-Jul-2019].

[17] "Top 50 Lean Tools - Comprehensive List for Lean Manufacturing and Service," *Lean*

Manufacturing Tools, 2019. [Online]. Available: http://leanmanufacturingtools.org/top-50-lean-tools-comprehensive-list-for-lean-manufacturing-and-service/. [Accessed: 02-Jul-2019].

[18] digité, "What is Kanban? Comprehensive Overview of the Kanban Method," *www.digite.com*, 2019. [Online]. Available: https://www.digite.com/kanban/what-is-kanban/. [Accessed: 02-Jul-2019].

[19] R. Sundar, A. N. Balaji, and R. M. Satheeshkumar, "12th GLOBAL CONGRESS ON MANUFACTURING AND MANAGEMENT , GCMM 2014 A Review on Lean Manufacturing Implementation Techniques," vol. 97, pp. 1875–1885, 2014, doi: 10.1016/j.proeng.2014.12.341.

[20] F. Harrison, "Getting started with Kanban," *Methods Ecol. Evol.*, vol. 2, no. 1, pp. 1–10, 2011, doi: 10.1111/j.2041-210X.2010.00056.x.

[21] R. Álvarez, R. Calvo, M. M. Peña, and R. Domingo, "Redesigning an assembly line through lean manufacturing tools," *International Journal of Advanced Manufacturing Technology*, vol. 43, no. 9–10. pp. 949–958, 2009, doi: 10.1007/s00170-008-1772-2.

[22] F. Ebook, "THE ULTIMATE GUIDE TO ELEARNING Table of Contents."

[23] T. Southworth, "Gemba walk," *Label Narrow Web*, no. 4, pp. 38–39, 2012.

[24] J. J. Forest, "Walk the Line," *Process Saf. Prog.*, vol. 34, no. 2, pp. 126–129, 2015, doi: 10.1002/prs.11724.

[25] James Lopresti, "What is a Gemba Walk and Why is it Important?," *Six Sigma Daily*, 2018. [Online]. Available: http://web.archive.org/web/20191107185437/https://www.sixsigmadaily.com/what-is-a-gemba-walk/. [Accessed: 12-Jan-2019].

[26] J. Prause, "Digitization vs. Digitalization – Wordplay or World View?," *sap.com*, 2016. [Online]. Available: https://news.sap.com/2016/05/digitization-vs-digitalization-wordplay-or-world-view/. [Accessed: 15-Apr-2019].

[27] "Digitalization," *Gartner IT Glossary*, 2019. [Online]. Available: http://web.archive.org/web/20191107185920/https://www.gartner.com/en/information-technology/glossary/digitization. [Accessed: 02-Mar-2019].

[28] J. Bloomberg, "Digitization, Digitalization, And Digital Transformation: Confuse Them At Your Peril," *https://www.forbes.com*, 2018. [Online]. Available: https://www.forbes.com/sites/jasonbloomberg/2018/04/29/digitization-digitalization-and-digital-transformation-confuse-them-at-your-peril/#22eb17a22f2c. [Accessed: 15-Apr-2019].

[29] "Digitization, digitalization and digital transformation: the differences," *https://www.i-scoop.eu*, 2018. [Online]. Available: https://www.i-scoop.eu/digitization-digitalization-digital-transformation-disruption/. [Accessed: 15-Apr-2019].

[30] D. Vuksanović, J. Ugarak, and D. Korčok, "Industry 4.0: the Future Concepts and New Visions of Factory of the Future Development," no. January 2016, pp. 293–298, 2016, doi: 10.15308/sinteza-2016-293-298.

[31] K. Witkowski, "Internet of Things, Big Data, Industry 4.0 - Innovative Solutions in Logistics and Supply Chains Management," *Procedia Eng.*, vol. 182, pp. 763–769,

2017, doi: 10.1016/j.proeng.2017.03.197.

[32] J. Dregger, J. Niehaus, P. Ittermann, H. Hirsch-Kreinsen, and M. Ten Hompel, “The digitization of manufacturing and its societal challenges: A framework for the future of industrial labor,” *2016 IEEE Int. Symp. Ethics Eng. Sci. Technol. ETHICS 2016*, pp. 1–3, 2016, doi: 10.1109/ETHICS.2016.7560045.

[33] Y. XIONG and Z. YIN, “Digital manufacturing—the development direction of the manufacturing technology in the 21st century,” *Front. Mech. Eng. China*, vol. 1, no. 2, pp. 125–130, 2006, doi: 10.1007/S.

[34] P. O’Donovan, K. Leahy, K. Bruton, and D. T. J. O’Sullivan, “An industrial big data pipeline for data-driven analytics maintenance applications in large-scale smart manufacturing facilities,” *J. Big Data*, vol. 2, no. 1, pp. 1–27, 2015, doi: 10.1186/s40537-015-0034-z.

[35] Y. Lu, “Industry 4.0: A survey on technologies, applications and open research issues,” *J. Ind. Inf. Integr.*, vol. 6, pp. 1–10, 2017, doi: 10.1016/j.jii.2017.04.005.

[36] A. Rojko, “Industry 4.0 Concept : Background and Overview,” vol. 11, no. 5, pp. 77–90, 2017.

[37] N. Ivezic, B. Kulvatunyou, and V. Srinivasan, “On architecting and composing through-life engineering information services to enable smart manufacturing,” *Procedia CIRP*, vol. 22, no. 1, pp. 45–52, 2014, doi: 10.1016/j.procir.2014.07.004.

[38] J. Hundley, “Industry 4.0 Compliant Weighing Solutions,” 2016. [Online]. Available: https://hammelscale.com/industry-4-0/. [Accessed: 19-Jul-2019].

[39] S. Vaidya, P. Ambad, and S. Bhosle, “Industry 4.0 - A Glimpse,” *Procedia Manuf.*, vol. 20, pp. 233–238, 2018, doi: 10.1016/j.promfg.2018.02.034.

[40] M. A. Norris, “The Next Phase Of Digitization In Manufacturing,” *Manuf. Bus. Technol. Rockaw.*, pp. 1–3, 2016.

[41] K. Ashton, “That ’ Internet of Things ’ Thing,” *RFiD J.*, vol. 22, pp. 97–114, 2009.

[42] M. Aiman Kamarul Bahrin, F. Othman, N. Hayati Nor Azli, and M. Farihin Talib, “Industry 4.0: A Review on Industrial Automation and Robotic,” *J. Teknol.*, vol. 78, no. 1, 2016, doi: 10.11113/jt.v78.9285.

[43] Y. Liao, F. Deschamps, E. de F. R. Loures, and L. F. P. Ramos, “Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal,” *Int. J. Prod. Res.*, vol. 55, no. 12, pp. 3609–3629, 2017, doi: 10.1080/00207543.2017.1308576.

[44] European Commission, *Factories of the Future*. Luxembourg: EFFRA, 2013.

[45] European Commission, “The Factories of the Future,” 2015. [Online]. Available: https://ec.europa.eu/digital-single-market/en/factories-future. [Accessed: 03-Nov-2018].

[46] R. Y. Zhong, X. Xu, E. Klotz, and S. T. Newman, “Intelligent Manufacturing in the Context of Industry 4.0: A Review,” *Engineering*, vol. 3, no. 5, pp. 616–630, 2017, doi: 10.1016/J.ENG.2017.05.015.

[47] B. Mrugalska and M. K. Wyrwicka, “Towards Lean Production in Industry 4.0,”

Procedia Eng., vol. 182, pp. 466–473, 2017, doi: 10.1016/j.proeng.2017.03.135.

[48] F. Tao, Q. Qi, L. Wang, and A. Y. C. Nee, "Digital Twins and Cyber–Physical Systems toward Smart Manufacturing and Industry 4.0: Correlation and Comparison," *Engineering*, no. xxxx, pp. 1–9, 2019, doi: 10.1016/j.eng.2019.01.014.

[49] R. H. Rawung and A. G. Putrada, "Cyber physical System: Paper survey," in *International Conference on ICT for Smart Society (ICISS): "Smart System Platform Development for City and Society, GoeSmart 2014",* 2014, pp. 273–278, doi: 10.1109/ICTSS.2014.7013187.

[50] S. A. Lee, E. A., & Seshia, *Introduction to Embedded Systems. A Cyber-Physical Systems Approach. Second Edition*, vol. 195. 2017.

[51] H. Kaartinen, S. Pieska, and J. Vahasoyrinki, "Digital manufacturing toolbox for supporting the manufacturing SMEs," *7th IEEE Int. Conf. Cogn. Infocommunications, CogInfoCom 2016 - Proc.*, no. CogInfoCom, pp. 71–76, 2017, doi: 10.1109/CogInfoCom.2016.7804527.

[52] M. Helu and T. Hedberg, "Enabling Smart Manufacturing Research and Development using a Product Lifecycle Test Bed," *Procedia Manuf.*, vol. 1, pp. 86–97, 2015, doi: 10.1016/j.promfg.2015.09.066.

[53] S. C. Feng, W. Z. Bernstein, T. Hedberg, and A. Barnard Feeney, "Toward Knowledge Management for Smart Manufacturing," *J. Comput. Inf. Sci. Eng.*, vol. 17, no. 3, 2017, doi: 10.1115/1.4037178.

[54] K. Araszkiewicz and A. T. Bojarska, "Modern information management throughout a construction project life cycle – selected issues concerning digitization in construction and a case study," *Czas. Tech.*, vol. 8, 2017, doi: 10.4467/2353737xct.17.127.6878.

[55] E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini, and C. Weinhardt, "Designing microgrid energy markets: A case study: The Brooklyn Microgrid," *Appl. Energy*, vol. 210, pp. 870–880, 2018, doi: 10.1016/j.apenergy.2017.06.054.

[56] S. Azhar, "Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry," *Leadersh. Manag. Eng.*, vol. 11, no. 3, pp. 241–252, 2011.

[57] D. Bryde, M. Broquetas, and J. M. Volm, "The project benefits of building information modelling (BIM)," *Int. J. Proj. Manag.*, vol. 31, no. 7, pp. 971–980, 2013, doi: 10.1016/j.ijproman.2012.12.001.

[58] H. Lanotte, A. Ferreira, and A. M. Senghor, "Pull Flow Management with a Digitized Syn- chronous Sequencer in the Aeronautical Industry," in *International Colloquium on Logistics and Supply Chain Management (LOGISTIQUA)*, 2017, pp. 42–47, doi: 10.1109/LOGISTIQUA.2017.7962871.

[59] J. Summers, "What is EDI (Electronic Data Interchange)?," *EDI Basics*, 2015. [Online]. Available: http://www.edibasics.com/what-is-edi/. [Accessed: 28-Feb-2019].

[60] T. Hoppe, H. Eisenmann, A. Viehl, O. Bringmann, and D. S. Gmbh, "Shifting from Data Handling to Knowledge Engineering in Aerospace Industry," in *IEEE International Systems Engineering Symposium (ISSE)*, 2017.

[61] E. Cronkleton and D. Bubnis, "What Is the Average Walking Speed of an Adult?,"

https://www.healthline.com/, 2019. [Online]. Available: https://www.healthline.com/health/exercise-fitness/average-walking-speed. [Accessed: 31-Jan-2020].

[62] "Qr Code Generator," *https://www.qr-code-generator.com/*, 2019. [Online]. Available: https://www.qr-code-generator.com. [Accessed: 03-Feb-2019].

[63] Daniel Nations, "Google Tasks Explained," 2019. [Online]. Available: https://www.lifewire.com/google-tasks-4149414. [Accessed: 15-Mar-2019].

[64] "Organize life," 2019. [Online]. Available: https://todoist.com/. [Accessed: 15-Mar-2019].

[65] "Take great notes," 2019. [Online]. Available: https://evernote.com/basic. [Accessed: 15-Mar-2019].

[66] "Wunderlist," *wunderlist.com*, 2019. [Online]. Available: https://www.wunderlist.com/. [Accessed: 15-Mar-2019].

[67] "Microsoft To-Do," 2019. [Online]. Available: https://to-do.microsoft.com/en-us. [Accessed: 15-Mar-2019].

[68] "Bear," 2019. [Online]. Available: https://bear.app. [Accessed: 15-Mar-2019].

[69] H. Field, "The 5 Best To-Do List Apps to Boost Your Productivity," 2018. [Online]. Available: https://www.entrepreneur.com/article/312312. [Accessed: 15-Mar-2019].

[70] "Digital Note-taking, Simplified!," 2019. [Online]. Available: http://www.noteshelf.net/. [Accessed: 15-Mar-2019].

[71] G. Hull, "Should you build a native app or a web app?," *Enabled Solutions*, 2018. [Online]. Available: https://medium.com/enabled-innovation/why-native-apps-are-better-than-web-apps-604867b20c50. [Accessed: 14-Aug-2019].

[72] Annie Dossey, "A Guide to Mobile App Development: Web vs. Native vs. Hybrid," *clearbridgemobile.com*, 2019. [Online]. Available: https://clearbridgemobile.com/mobile-app-development-native-vs-web-vs-hybrid/. [Accessed: 14-Aug-2019].

[73] "Maximo Nextgen REST API," *ibm.com*, 2018. [Online]. Available: https://developer.ibm.com/static/site-id/155/maximodev/restguide/Maximo_Nextgen_REST_API.html. [Accessed: 15-Aug-2019].

[74] "Input Checkbox checked Property," *w3schools.com*, 2019. [Online]. Available: https://www.w3schools.com/jsref/prop_checkbox_checked.asp. [Accessed: 15-Aug-2019].

[75] "HTML Iframes," *w3schools.com*, 2019. [Online]. Available: https://www.w3schools.com/html/html_iframe.asp. [Accessed: 15-Aug-2019].

[76] "<iframe>: The Inline Frame element," *MDN web docs*, 2019. [Online]. Available: https://developer.mozilla.org/en-US/docs/Web/HTML/Element/iframe. [Accessed: 15-Aug-2019].

[77] M. Rouse, "IFrame (Inline Frame)," *TechTarget*, 2015. [Online]. Available: https://whatis.techtarget.com/definition/IFrame-Inline-Frame. [Accessed: 15-Aug-

2019].

[78] “Anseo Suite,” *ivertec broadband*, 2018. [Online]. Available: https://www.ivertec.ie/anseo/. [Accessed: 15-Aug-2019].

[79] “Time & Attendance Tracking Solutions,” *BarcodesEDGE*, 2019. [Online]. Available: https://www.barcodesinc.com/barcodesedge/solutions/access-control-security/time-attendance/. [Accessed: 15-Aug-2019].

[80] “Student Card Readers,” *SEAtS Software*, 2019. [Online]. Available: https://www.seatssoftware.com/student-card-reader/. [Accessed: 15-Aug-2019].

[81] Shana Pearlman, “What are APIs and how do APIs work?,” *MuleSoft.com*, 2016. [Online]. Available: https://blogs.mulesoft.com/biz/tech-ramblings-biz/what-are-apis-how-do-apis-work/. [Accessed: 15-Aug-2019].

[82] “Digital Pens,” *Yifang Digital*, 2013. [Online]. Available: http://www.yifangdigital.com/product/xn811.aspx.

[83] B. L. Skaggs, J. W. Poe, and K. W. Stevens, “One-stop shopping: A perspective on the evolution of electronic resources management,” *OCLC Syst. Serv.*, vol. 22, no. 3, pp. 192–206, 2006, doi: 10.1108/10650750610686243.